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The Human Factors Relating to Escape and Survival from Helicopters Ditching in Water

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ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARDograph No.305(E)

THE HUMAN FACTORS RELATING TO ESCAPE AND SURVIVAL FROM HELICOPTERS DITCHING IN WATER

by

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PREFACE

One miserable Saturday in March 1977, I was lowered from a Sea King Helicopter to the pitching deck of a small Canadian stern trawler some 80 miles east of Louisburg, Nova Scotia. One of the deck hands had suffered a penetrating wound to the abdomen and required urgent medical attention.

The journey was far from simple; we flew through sun, snow, sleet and fog and arrived on station only to find that the Master could not control the speed of his vessel in the heavy seas. This made hoisting very difficult and brought us to the edge of our hovering time very quickly despite the fact that we had "hot fuelled" in Sydney enroute.

I quickly developed a healthy respect for the professional skills of the aircrew, particularly as I hung dependent at the end of a horse collar over mid-ocean. I was also very surprised to learn how ill-equipped and ill-prepared the modern helicopter is for survival at sea in the event of ditching.

This began my personal interest in helicopter escape and survival and I began to examine the problems in more detail. This AGARDograph is the result.

It describes the worldwide incidence of military and civilian over-water helicopter accidents and the problems related to survival. It reviews the typical accident scenario from the moment the occupant steps on board the helicopter and the pre-flight briefing through to the accident itself, the escape (commonly from underwater and in darkness), to the rescue and return safe and sound to dry land. It also proposes improvements to helicopter crashworthiness, life support equipment and a syllabus for underwater escape training. It is dedicated to all maritime aviators who fly over the sea for their living and in particular to Captain Stewart Russell and Captain George Smith of the Canadian Forces who dropped me into the fishing nets and rigging of the trawler on that appalling afternoon of the Eastern Canadian Seaboard.

• • •

Un malheureux samedi du mois de mars 1977, l'on m'a hélitreuillé en "Sea King" sur le pont d'un chalutier Canadien navigant a quelques 80 milles au large de Louisburg, Nouvelle Escosse. L'un des hommes de pont avait subi une blessure profonde à l'abdomen nécessitant des soins médicaux d'urgence.

Le voyage fut loin d'être simple; au cours du vol, nous avons été confrontés au soleil, à la neige, au grésil, au brouillard, et, arrivés sur place, nous avons constaté que le commandant du chalutier était incapable de contrôler sa vitesse, tellement la mer était houleuse. Les opérations de hissage se sont avérées très difficiles et nous avons très vite épuisé notre potentiel de vol stationnaire, malgré le fait que nous avions effectué un ravitaillement en carburant en urgence à Sydney, en cours de route.

Suspendu au-dessus de l'océan, au bout de l'élingue de sauvetage, j'ai eu tres vite l'occasion d'admirer le professionalisme de l'équipage de l'hélicoptère. J'étais en même temps étonné de voir à quel point les hélicoptères modernes sont mal équipés et mal préparés pour la survie en cas d'amérissage.

Ainsi est né ma motivation personnelle pour les problèmes d'évacuation et de survie des équipages d'hélicoptère et par la suite j'ai commencé a approfondir la question. La présente AGARDographie en est le résultat.

Elle décrit l'incidence des accidents survenant dans le monde aux hélicoptères civils et militaires au-dessus de l'eau et les problèmes de survie. Elle examine le scénario type d'un tel accident à partir du moment où la personne transportée monte a bord de l'hélicoptère, le briefing avant vol, l'accident lui-même, l'évacuation (le plus souvent en hélicoptère immergé et dans le noir), le sauvetage, et enfin le retour sain et sauf sur la terre ferme. Elle propose également certains améliorations qui seraient à apporter dans le domaine de la résistance au crash des hélicoptères et les équipements de survie, ainsi qu'un programme de cours sur l'évacuation sous l'eau. Elle est dédiée a tout aviateur qui survole la mer pour gagner sa vie, et en particulier au Capitaine Stewart Russell et au Capitaine George Smith des forces armées Canadiennes qui m'ont fait descendre dans les filets et les haubans du chalutier cet après-midi épouvantable au large du littoral Est du Canada.

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CHAPTER 1:

INTRODUCTION

1.1 The Problem

When a helicopter ditches into water, it usually inverts and rapidly sinks. With water rushing in through cockpit windows, aircrew and passengers have to overcome inherent buoyancy to make their escape from a flooded compartment through cargo doors, access doors, windows or the windshield. They may even be thrown out through a split in the cabin if the impact is severe. Even if the crew and passengers are uninjured, escape is difficult with the loss of vision, the disorientation, the requirement to not breath underwater in spite of the gasp reflex and the extreme terror created by the catastrophe (6, 8, 12, 13, 17, 24, 25, 41, 60, 63, 65, 66). Occupants whose passage is blocked by entanglement with debris, who cannot release their lap straps, or who are injured, commonly perish (24).

Although the problem of underwater escape has been present since the first aircraft flew over water, it was less severe in the early days, because aircraft were lightly constructed and usually floated. Aircrew and passengers had time to escape before complete submersion. Even World War II aircraft tended to float long enough for aircrew to escape (24). Immediately after the war, due to the greater water impact velocity of faster-flying aircraft, it became highly unlikely for the aircrew to escape following impact and rapid submersion.Consequently, ejection seats were introduced into fixed wing fighter aircraft, which improved the chance of survival where ejection was initiated before water impact.

The introduction of the helicopter has produced unique problems related to survival after impacts particularly underwater escape for aircrew and passengers. Although helicopters tend to be lighter and more buoyant than fixed-winged aircraft, after ditching they either float upright (Figure 1), float inverted (Figure 2) or sink inverted. Unfortunately, unless there is a very calm sea state, the latter two situations occur more frequently and are more likely to result in loss of life. For instance, the Sikorski S61 is designed to stay afloat (if intact) up to conditions of Sea State 3; yet in the North Sea,where it is very commonly used, the sea state exceeds 3 for much of the year.

This chapter reviews worldwide statistics on both civilian and military helicopter accidents over water and the corresponding incidence of escape. The following chapters examine the causes of fatalities, discuss solutions and recommend research and development that is required to improve the survival rate. Criteria for categorizing accidents vary between nations so, for consistency, single-engined landings in water and semi-controlled ditchings are also considered as accidents/ditchings.

1.2 Statistics on Over Water Helicopter Accidents

1.2.1 Military Experiences

The United States Navy (USN) has so far published the largest study of over water helicopter accidents in three separate series of papers and one short article. The first study by Rice and Greear (60) examined accidents that occurred over a four-year period (1969-1972). They reported 78 accidents which involved the loss of 63 lives. Ten deaths were due to injuries while 25 were attributed to drowning; the remainder were categorized as "lost at sea". Twenty-one of those recovered, drowned, or lost at sea were last seen still in the aircraft. Ten of these 78 helicopters neither floated nor sank but rested on the bottom partially submerged in shallow water, yet nine men still lost their lives. Five helicopters disintegrated on impact and 41 sank immediately, accounting for 26 fatalities. Twenty-five accidents resulted in fatalities. There were no survivors in five of these accidents; in the other 20, there were 72 survivors and 44 fatalities. Of the 44, death was attributed to drowning in 22, 15 more were lost at sea and never recovered, and the remaining seven suffered fatal injuries. The survivors of these accidents reported in-rushing water as the main problem in escaping from the aircraft. This, often coupled with disorientation and inability to either reach or open escape hatches, was reported by 36 (50%) of the survivors.

A second study encompassing the Rice and Greear statistics was carried out by Cunningham (24) using the U.S. Navy Safety Centre statistics from July 1963 to February 1975. During this period, 234 helicopters with a total of 1,093 occupants either crashed or were ditched at sea. The survival rate was 82%; 196 persons died in those accidents, of which 130 were listed as lost/unknown, 29 suffered either a fatal injury or an injury which caused drowning, and the remaining 37 were not injured but drowned nevertheless. Of 897 survivors, 437 (49%) egressed from underwater; they all encountered multiple problems, such as inrushing water, disorientation, panic, entanglement with debris, and unfamiliarity with existing release mechanisms. These will be discussed in Chapter Two.

In a paper on underwater breathing apparatus (26), Eberwein referenced the above statistics and also updated the information with brief statistics on the frequency in which USN helicopters ditched at sea for the years 1978-1983. In this time period, 72 helicopters were involved with 330 occupants. No survival rates were published.

Since then, Thornton from the USN Safety Centre has compiled and will soon

Figure 1. Typical helicopter accident where the helicopter barely floats upright.

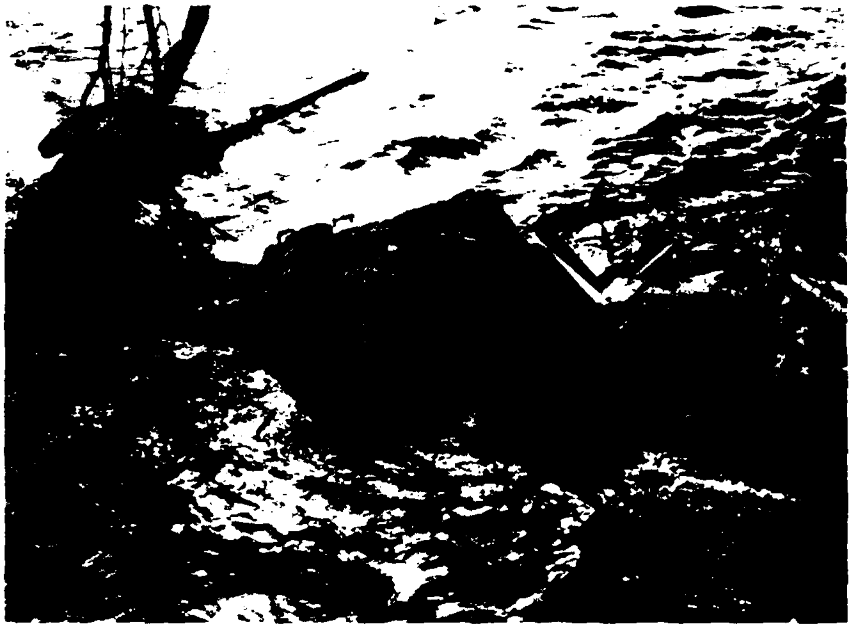
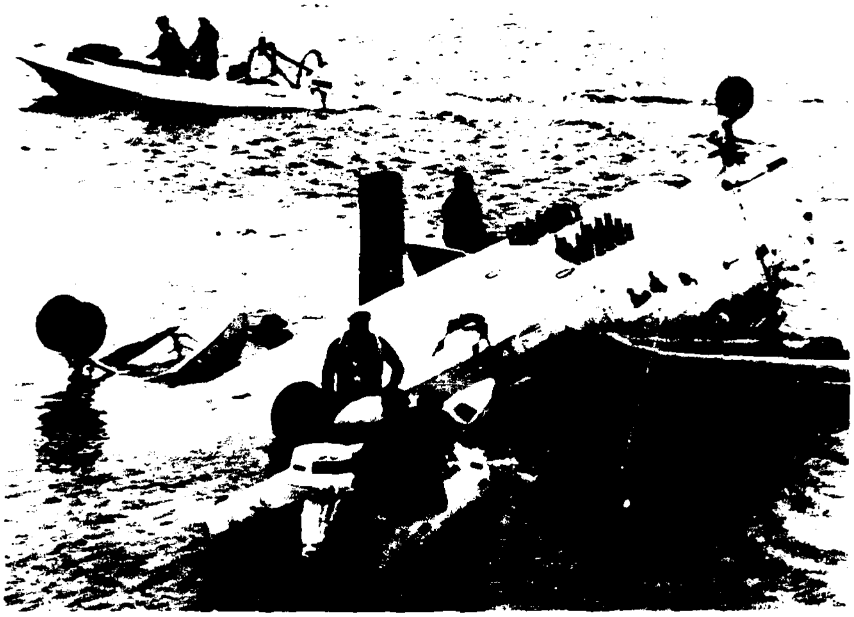


Figure 2. Typical helicopter accident where the helicopter sinks and is rapidly inverted.



publish data for the period from 1984 through to 1986 (19). In this period, there have been 39 over water accidents involving a total of 219 occupants. There were 66 fatalities for an overall survival rate of 70%; individual, yearly survival rates for 1984, 19[illegible] and 1986 were 77%, 52% and 80%, respectively. Of the 66 fatalities, 18 (27%) individ[illegible] drowned, five others probably drowned lost at sea, and 21 probably died from a fatal [illegible]ct (also lost at sea). Thornton's preliminary figures for 1987 list an additio[illegible] 28 cases in which personnel had to make an underwater escape. The latest U.S.N. statistics for Helicopter Water Escape in 1987 and cumulative figures for 1982-1986 are presented in Table 1, 2 and 3.

Table 1: U.S.N. Helicopter Water Escape CY 1987
(Courtesy of the U.S. Navy Safety Centre)

Type	Total Mishaps		Total Occupants		Total Fatalities		Survival Rate	
	Day	Night	Day	Night	Day	Night	Day	Night
AH-1	-	-	-	-	-	-	-	-
UH-1	-	1	-	4	-	1	-	75%
H-2	1	1	3	3	-		100%	100%
H-3	2	2	13	7	4	1	69%	86%
H-46	3	-	12	-	4	-	67%	-
H-53	1	-	16	-	-	-	100%	-
H-60	-	-	-	-	-	-	-	-
Total	7	4	44	14	8	2	82%	86%

Table 2. U.S.N. Helicopter Water Escape - Cumulative 1978 - 1982
(Courtesy U.S. Navy Safety Centre)

Type	Total Mishaps		Total Occupants		Total Fatalities		Survival Rate	
	Day	Night	Day	Night	Day	Night	Day	Night
AH-1	2	1	4	2	4	2	0%	0%
UH-1	5	1	23	3	7	-	70%	100%
H-2	6	2	20	7	2	1	90%	86%
H-3	17	6	83	24	11	-	87%	100%
H-46	11	6	59	22	10	14	83%	36%
H-53	4	1	31	5	9	5	71%	0
Totals	45	17	220	63	43	22	80%	65%

Table 3. U.S.N. Helicopter Water Escape - Cumulative 1982 - 1986
(Courtesy U.S. Navy Safety Centre)

Type	Total Mishaps		Total Occupants		Total Fatalities		Survival Rate	
	Day	Night	Day	Night	Day	Night	Day	Night
AH-1	1	1	2	2	2	1	0%	50%
UH-1	4	1	17	3	-	3	100%	0%
H-2	8	8	32	28	1	9	97%	68%
H-3	8	8	35	34	-	1	100%	97%
H-46	8	3	52	25	14	19	73%	24%
H-53	6	-	44	-	30	-	32%	-
H-57	-	-	-	-	-	-	-	-
H-60	2	1	7	3	2	-	71%	100%
Totals	37	22	189	95	49	33	74%	65%

Brooks recently published the Canadian statistics for Canadian aircrew, excluding the Royal Canadian Navy, for the years 1952 - 1987 (10,11). Of a total of 97 accidents of all types of aircraft in fresh and sea water, 16 (16%) were helicopters. There were 60 personnel involved and the overall survival rate was 77%, which is comparable to the USN figures. Of 14 fatalities, nine were from serious injury and five were probably from a combination of injury and drowning.

The United Kingdom have also recently published their military helicopter accident statistics. Vyrnwy-Jones first reviewed all Royal Air Force helicopter accidents that occurred from 1971-1983 (77). He reported 45 major accidents in which there were 16 fatalities. Four ditchings (9%) were into the sea - three Whirlwind pilots managed to conduct controlled ditchings, and one Wessex pilot lost control through disorientation. Of significance is the fact that each of these four helicopters rolled over and rapidly sank after impact. Very fortunately there were no fatalities in the total of 13 crew involved.

Following this review, Vyrnwy-Jones and Turner completed a study of all Royal Navy helicopter accidents from 1972-1984 (78). In this series there were 121 helicopter accidents, of which 53 involved ditching or crashing into the sea. This included two Sea King helicopters involved in a mid-air collision - one was able to make a more or less controlled ditching, but the other was badly damaged and fell into the sea out of control. This was considered as one accident. The injuries suffered by the latter crew during the collision were such that it was not possible to prepare for the ditching. A second mid-air collision between two RN Gazelle helicopters was also considered as one accident; both were badly damaged and fell into the sea out of control. There were 191 survivors and 34 fatalities in the 121 ditchings - 20 of the fatalities were in one Sea King accident and eight others were in the two mid-air collisions. In 47% of cases, the helicopter either sank or rolled immediately after water impact, and after rolling it either sank quickly or remained afloat inverted. In other words, nearly one-half the aircrew and passengers had to make some form of under-or in-water escape. In a further 21% of cases, the helicopter sank or rolled over and then sank soon after the crew and passengers had escaped. These figures show that helicopters are extremely unstable in water, even in good sea conditions, and also that crew and passengers will likely have to escape while in or under water. Moreover, Baker and Harrington (9) found that escape difficulties have been noted in 35% of the cases (1 of 14 Wessex, 2 of 9 Wasp, 11 of 18 Sea King, and 1 of 2 Lynx).

Between 1983 and 1987 the Australian Defence Force (57) has experienced four helicopter (three Navy, one Air Force) ditchings into the sea. There were a total of 23 survivors and 3 fatalities. The crew had to make an under-or in-water escape in two cases - in a Wessex helicopter which rolled and quickly submerged, and in a Chinook which sank rapidly upright.

The Norwegian Air Force (55) have had three helicopter accidents in water in the period from 1977 to December 1987. One helicopter sank upright rapidly, one rolled over and sank inverted rapidly, and the other likely disintegrated due to high speed impact with the sea following loss of control. There were seven survivors and four fatalities. In two of the cases, surviving crew had to escape from in or under water.

Denmark have only two helicopters that ditched in water (53). The first was a Lynx with three personnel on board, and all escaped with no injury. The second was a Sea King helicopter that crashed into very shallow water and broke up on impact, killing all five personnel. Landing in water was not a factor in these fatalities.

The Dutch Navy have had four accidents involving five helicopters (52). All five helicopters sank rapidly after ditching, 12 personnel were involved and four died. Two Wasp AH-12A helicopters were flying in formation when their main rotors touched. Both ditched from an altitude of 200 feet. All four crew successfully escaped, however two had spinal injuries. The second accident was the case of another Wasp that stalled on take-off from the ship; it ditched in a controlled manner and the two crew egressed very quickly with no problem. The third accident was the case of a Lynx which ditched into the sea while practicing night approaches to the ship; it rapidly sank inverted, only the two pilots managed to egress and the one passenger did not escape. It was noted that the passenger had not undergone underwater escape training. The fourth and last Dutch helicopter accident was the case of a second Lynx. The crew were practicing an automatic hover at 60 feet where it is hypothesized that something went wrong with the automatic hover control. All three crew were killed on impact.

Sweden reported two helicopter accidents into water since the mid-1970s. The first was a Boeing Vertol 107 that force-landed in the Stockholm archipelago because of low oil pressure to the rotorhub. The helicopter floated well and there was no problem with the escape of the crew. The second incident occurred in the Baltic Sea off southern Sweden; in this case, the pilot of a Bell 206 made a controlled ditching and the crew again escaped without any problem.

Other European statistics come from France where l'Aviation Légère de l'Armée de Terre reported four helicopter accidents into water since 1955. The first was a Bell 47G which had a rotor failure; the student pilot and instructor landed on the edge of a lake partially submerged in water with the helicopter inverted. Both escaped with no problem. The second helicopter was a Djinn in which the pilot had to make a ditching into the Mediterranean. The helicopter quickly inverted and the Chief crewman had no problem making an underwater escape; however he had to dive back into tre cabin to release the pilot inverted underwater, hung up by his microphone cord. The third helicopter was an Alouette II which had an engine failure and crashed into the Atlantic Ocean. All four occupants had multiple bruises; one passenger had difficulty releasing the seat belt and another had difficulty releasing a foot trapped under the seat. The fourth and last accident was a Puma 330 that crashed into the Mediterranean Sea from approximately 2500 metres following a possible engine failure. The crash was unsurvivable and all six occupants were killed.

1.2.2 Civilian Experience

The survival rate of helicopter ditchings into water for civilian operations is similiar to that for military operations. For instance, in the North Sea, Anton (8) reported on seven civilian helicopters that ditched from January 1970 to November 1983. There was only one fatality in this series, although the condition of survivors in two of the seven accidents became marginal due to hypothermia. One passenger was originally thought to be badly shocked but was later diagnosed as seasick. Anton's findings indicated a correlation between sea state and probability of injury, structural damage and capsizing. In three of his seven cases, the helicopter capsized either immediately after striking the water, or very shortly afterwards. In a report by E&P Forum (75) in 1987, it was observed that there is, on average, one transport helicopter ditching per year in the North Sea. There were four ditchings from 1970 to 1977 and eight ditchings from 1981 to 1986. The most recent accident, in July 1988, was a Sikorsky S61 ditching following an engine fire - all 19 crew and passengers egressed successfully.

Elliot (50) made the following observations on 12 of these North Sea accidents occuring from 1970-1986, (information on the remaining four accidents is not yet available). The overall rate of survival following ditching was 62%; six ditchings were controlled and six were crashes. No fatalities occurred following a controlled ditching. Of the 108 people involved in the six crashes, only 21 survived, five of the helicopters sank, four floated upright and the other three floated inverted.

In 1984, the British Airworthiness Requests Board reviewed Helicopter Certification Standards and accident statistics (59); they concluded that:

a. helicopter accident rates, either on a per hour or per flight basis, are significantly worse than those for modern jet transports, but are comparable to those for propeller turbine transports;

b. the percentage of accidents that is due to airworthiness causes is greater for helicopters than for fixed-wing airplanes;

c. the percentage of accident with airworthiness causes and which prove fatal is significantly higher for helicopters than for fixed-wing airplanes; and

d. helicopters which have had the benefit of military operations before entering civilian operations have a better accident record in their early years of service than the one helicopter which was never used in military operations, but sold directly to civilian operators.

The most up-to-date statistics for European over water civilian helicopter accidents has been recorded by Ferguson of Rotor and Wing International, Aberdeen (51). He has maintained records since 1969 on all helicopters that have ditched into the North Sea and off the coast of the British Isles. A complete list is presented in Table 4 grouped by country of origin. From 1969 until September 1987, there have been 28 ditchings. In 17 accidents, there were no fatalities but in the remaining 11, there was a loss of 112 lives. The overall survival rate was 68%.

Of the 28 European accidents, 20 were in the British sector. 45 personnel were killed in one Chinook accident east of Sumburgh Airport following a gearbox failure. Twenty were killed in a Sikorski S61 accident after the crew became disoriented in fog and flew into the sea en-route Penzance to the Scilly Isles. Thirteen were killed in a Wessex accident off the Norfolk Coast, likely following a mechanical failure. There were nine fatalities in three Bell 212 helicopters - one fatality following pilot disorientation south of the Dunlin Field; six in an accident near the Murchison Field following a series of events, including bad weather and mechanical problems; and two northeast of the Humber River after the helicopter flew into the sea, likely as a result of mechanical problems.

In the Norwegian sector, there have been five ditchings. Eighteen personnel were killed in a Sikorski S61 which sank in pieces southwest of Stavanger following a main rotor spindle failure. Twelve were killed in another Sikorski S61 which also sank in pieces southwest of Stavanger. The cause was not established. Four personnel were killed in a third Sikorski S61 southwest of Stavanger, following a tail rotor gearbox failure. The helicopter floated for only a very short time, then capsized rapidly. The Norwegian Aircraft Accident Commission identified one additional sea water accident not in Ferguson's statistics - the case of a Hughes 369 which ran out of fuel and crashed into a fiord north of Trondheim with the loss of the single pilot occupant.

In the Danish sector, there has been only one accident, that of a Bell 212 caused by a tail rotor failure. The helicopter sank rapidly following impact 22 miles east of

Table 4. List of Civilian Helicopters Ditched into the North Sea or off the Coast of the British Isles 1969 - 1987. (Courtesy of J.D. Ferguson, Rotor and Wing International)

HELICOPTER		DATE	SURVIVED	FATAL	ACCIDENT SITE	CAUSE
United Kingdom						
Bristow						
S-55T	G-AOHE	12/06/69	3		E of Gt Yarmouth	Engine failure
S-61N	G-AZNE	04/04/73	1		NE of Aberdeen	Excessive deck movement
B206A	G-AXKE	01/08/75	1		Forties Field	Fuel shortage?
Wessex	G-ATSC	08/03/76	14		E of Bacton	Intake covers not removed?
S-61N	G-BBHN	01/10/77	3		NE of Aberdeen	Main rotor blade pocket failure
B212	G-BIJF	12/08/81	14	1	S of Dunlin Field	Pilot disorientation
Wessex	G-ASWI	13/08/81	13	13	Off Norfolk Coast	Mechanical failure?
B212	G-BDIL	14/09/82	6	6	N Murchison Field	Night SAR-bad weather
B212	G-BARJ	24/12/83	2		Brent Field	Winch cable snagged during training
B212	G-BJJR	20/11/84	4	2	NE of Humber	Flew into sea-mechanical failure
British Caledonian						
B214ST	G-BKFN	15/05/86	20		NE of Fraserburgh	Main rotor collective problem
British Airways International						
S-61N	G-ASNM	15/11/70	3		E of Aberdeen	Main gearbox oil leak
S-61N	G-BEID	31/07/80	15		ESE of Aberdeen	Oil cooler drive belt failure
S-61N	G-ASNL	11/03/83	17		NE of Aberdeen	Main gearbox failure
S-61N	G-BEON	16/07/83	26	20	Penzance/Scillies	Flew into sea in fog
Chinook	G-BISO	02/05/84	47		Cormorant Field	Double hydraulic failure
Chinook	G-BWFC	06/11/86	47	45	E of Sumburgh Airport	Crashed into sea - gearbox failure
S-61N	G-BEID	13/07/88	21		E of Bressay	Ditched, sank-engine failure
Management Aviation						
B0105	D-HDGB	12/07/76	4		Off E Anglia	Engine failure - ditched
Bond						
B0105	G-AZOM	24/07/84	3 or 4		Off Hunstanton	Tail rotor failure
Denmark						
Maersk						
B212	OY-HMC	02/01/84	3	3	22nm E of Dan B	Tail rotor failure
Netherlands						
KLM						
S-61N	PH-NZC	10/05/74	6	6	110nm N of Texel	Main rotor blade failure
Schreiner						
Daupin	PH-SSN	19/04/88	5		40nm off Rotterdam	Disorientation
Norway						
Helikopter Service						
S-61N	LN-OQA	09/07/73	17	4	SW of Stavanger	Tail rotor gearbox failure
S-61N	LN-OSZ	23/11/76	12	12	SW of Stavanger	No cause established
S-61N	LN-OOS	26/06/78	18	18	W of Bergen	Main rotor spindle failure
B212	SN-ORL	31/07/79	3		Off Stavanger	A/rotation accident
S Puma	LN-OMC	15/07/88	18		70nm Stavanger	Main rotor blade leading edge failure

Table 5. Condition of Civilian Helicopters ditched into the North Sea or off the coast of the British Isles 1969 - 1987
(Courtesy of J.D. Ferguson, Rotor and Wing International.)

HELICOPTER	SANK	FLOATED	MID-AIR BREAKUP
S55T			Unknown
S61N		Floated	
B206 A		Floated*	
Wessex		Floated*	
S61	Sank Inverted		
B212	Sank		
Wessex			Before hitting sea
B212	Sank		
B212		Barely	
B212	Sank		
214ST		Floated	
S61N		Eventually sank	
S61N		Floated	
S61N		Eventually sank	
S61N	Sank		
Chinook		Capsized in 1 hr	
Chinook			Crashed in pieces
S61N	Ditched, burned broke up & sank		
B0105			Unknown
B0105		Barely	
B212	Sank		
S61N	Sank		
Dauphin		Floated inverted	
S61N		Capsized quickly	
S61N	Sank in pieces		
S61N	Sank in pieces		
B212		Floated	
S Puma		Floated	

*Sank during salvage operation

oil rig 'Dan B', killing three personnel.

In the Dutch sector, there have been two accidents; the first was a Sikorsky S61, with a main rotor blade failure. It sank on impact 110 miles north of Texel, and six personnel were killed. The second was an H65 Dauphin in which the pilot became disorientated on approach to landing a ship; the helicopter flew into the sea, but floated inverted, all five occupants escaped from underwater.

In Ferguson's series (Table 5), only 14 helicopters (50%) floated, of which two barely floated, one floated inverted, one capsized "quickly", one capsized after an hour, two sank "eventually" (after some hours), and two sank during salvage operations. In the other 14 accidents, ten helicopters (37%) sank rapidly, one sank inverted and three sank with the fuselage broken into pieces. In two cases, the helicopter broke up in midair before hitting the sea and sinking. In two cases the condition of the helicopter at the time of impact with the sea could not be established.

Additional European statistics were submitted by the Swedish Board of Accident Investigation (Table 6). They have had six helicopter accidents into water since 1976. Eighteen personnel were involved and there were three fatalities. The first helicopter was a Hughes 269 in which the pilot was checking the river for drifting timber when the helicopter hit a power line, somersaulted and sank immediately. Two passengers drowned - probably knocked unconscious when hitting the water surface. The second was a Bell 47 in which the pilot on climb out suffered a partial power-loss at 40 metres altitude; landing could not be made at the shore line and the pilot continued out over the lake heading for a sight he knew was suitable. However, the power deteriorated further and the helicopter struck the water hard and sank immediately. The passengers were thrown clear, the pilot unbuckled his harness and stepped out, but unfortunately one passenger was knocked unconscious, sank and drowned before he could be rescued. The third helicopter was a Hughes 500 in which the pilot was emptying an underslung load of lime into a lake. The sack carrying the lime in a sling hit the tail rotor and the pilot being unable to control the helicopter made a successful emergency autorotation on to the lake surface, the helicopter later sank. The fourth was a Bell 205 in which the pilot was photographing a ferry leaving Trellborg Harbour; at 1500 metres, control of the helicopter was lost and the pilot made an emergency autorotation into the water. The helicopter floated upright and all three occupants successfully escaped with no difficulty. The fifth was a

Table 6: Swedish Civilian Helicopter Accidents 1976-1986
(Courtesy of the Board of Accident Investigation, Stockholm, Sweden)

	ACCIDENTS					
Registration Manufact/ Model	SE-HCI Hughes 269A	SE-HGO Hughes 500	SE-HHP Enstrom F 28A	SE-HIU Bell 205	SE-HME Bell 47	SE-HRD Bell 206A
Acc. date	1976 June 3	1984 Oct. 4	1987 June 19	1986 June 25	1982 Aug 21	1986 Sep. 16
Place	Kramfors	Järnlunden	Ingarö	Trelleborg hbr	Adolfström	Snåckedjupet
Flight phase	Survey low altitute	Lime spraying	Precaution landing	Photo flight	Initial climb	Photo low flt
No. of occupants	3	1	3	3	3	5
Floated upright				Yes		
inverted						Yes
Sank eventually		Yes				
at once	Yes		Yes		Yes	
Escaped with ease	1	1	3	3	2	3
hampered	-	-	-	-	-	1
Drowned stuck by safety belt	-	-	-	-	-	1
Fatality for other reasons	2	-	-	-	1	-

Bell 206A in which the pilot was also on a filming mission when the tail rotor hit a sea marker and the helicopter lost directional control. The pilot inflated the emergency floats in preparation for autorotation and water landing, they were punctured most likely on water impact and rendered useless, the helicopter floated inverted. The cameraman was sitting in the open doorway with an extra safety belt tied across the door frame to minimize the risk of falling out when handling the camera. He was unable to release himself and drowned. Three other occupants escaped with ease, but a fourth required assistance by the pilot to get out of the wreckage. The sixth and last helicopter was an Enstrom F28A in which the pilot experienced deteriorating weather and attempted a precautionary landing on the beach, the pilot lost control at very low speed and height, the helicopter struck the water and sank, the three occupants successfully escaped with no difficulty.

Statistics from the Canadian Aviation Safety Program of Transport Canada (54) show that there were 852 Canadian registered helicopter accidents in and offshore Canada from 1976-1987. Of 741 accidents for which the type of terrain was reported, 98 cases (13%) were in water. The degree of difficulty of post-crash escape was - no problem 23 (24%) cases, with difficulty 20 (20%) cases, undetermined two (2%) cases, not applicable six (6%) cases, and not coded in the computer 47 (48%) cases. There were 245 personnel involved with 47 fatalities - a survival rate of 80%.

Finally, 3 Australian civilian helicopters (each with a single pilot only) have ditched into the sea between 1969 and 1987 (57). A SK58E with tail rotor gearbox failure, a Bell 47 with transmission failure and a Bell 206B in which improper procedures caused the accident. There were no fatalities in any accident.

1.3 Summary

Five observations are clear from the data and associated reports. First, helicopters have had a greater accident rate than have fixed-wing aircraft. Second, helicopters ditching in water have a high fatility rate - in the range of 15-45%. Third, survivors will likely have to make an in or underwater escape because, on hitting the water even in the calmest sea, the helicopter is likely to flood and sink quickly, often rolling inverted. Fourth, approximately 35% of survivors have had great difficulty making their escape. And fifth, manufacturers have incorporated little current crashworthy technology into helicopters.

CHAPTER 2: SURVIVAL FACTORS

2.1 Introduction

The review of helicopter airworthiness (59) confirmed that the helicopter accident rates in the United Kingdom are significantly worse than for modern jet transport 2.0 vs 0.4 per 100,000 flying hours. The rate is also greater for helicopters on a per flight basis. A principal reason for the differences is that conventional aircraft reliability has been developed over 80 years of evolution compared to about 45 years since the end of the Second World War for helicopters. Duplication or redundancy of many critical mechanisms of a helicopter cannot be achieved. For example, there can only be a single lifting system, even though there can be be more than one engine. Helicopter rotor blades, rotor heads, engine mountings, controls and transmissions are particularly susceptible to fatigue. Disastrous results occur if the problem is not observed during maintenance, or if quality control of gearboxes is not of a high standard.

When an accident occurs, there is no systematic methodology applied to helicopters to improve their crashworthiness and the survivability of occupants, in spite of the fact that technology is now readily available to achieve both goals.

There are many reasons why the survival rate for helicopters ditching into water are 75% on average worldwide. Boeing Vertol conducted a study of helicopter ditchings in 1976 (41). Although dates were not indicated, the accidents of 200 Navy Marine helicopters of seven different types were reviewed. The helicopters all reacted similarly on ditching - more than 50% sank in less than 1 minute, all non-amphibious craft capsized before or during submergence, and almost all that sank did so nose first. It was noted that the helicopters reacted violently as the turning rotor blade hit the water. The fuselage often rocked from side to side and the fuselage sometimes would spin on its vertical axis like an unwinding gyro. As rotor rpm decayed and aircraft control was lost, the helicopter typically rolled inverted left or right, breaking or bending the rotor blades. The cabin began to fill with water, usually from the nose direction, since nose windows are not designed to withstand severe water impact.

In contrast to this, the new H65 Dauphin II, made by Aerospatiale of France and just accepted into U.S. Coastguard service, has inflatable buoyancy bags built into the fuselage so that it will float tail up. There has only been one accident in moderate seas in which the performance of this system has been examined and details are available. A Dutch Schreiner Airways H65 Dauphin helicopter recently had an accident in which the pilot became disorientated at night on approach to a ship and flew into the sea at a low speed. The helicopter floated inverted and the two crew and three passengers escaped successfully. There has been scanty information of two other very recent H65 accidents, one off Goa and one off Gabon. Details are not available at present, except it would appear that all lives were lost in both accidents and the helicopters broke up on impacting the sea.

If a helicopter is forced to ditch into the sea, then it should be capable of floating for a sufficient time to allow occupants to escape into liferafts. The Civil Aviation Authority (CAA) postulated that ten minutes was an adequate time for emergency egress, British Hovercraft (49) on behalf of the CAA conducted model tank experiments and concluded that the height of a breaking wave from crest to trough that would overturn a floating helicopter was 1.75 metres. The CAA then asked the Institute of Oceanographic Sciences (IOS) to estimate the probability of a ditched helicopter encountering a breaking wave of greater than 1.75 meters in any 10 minute. The IOS study (22) of sea states off the coast of the British Isles and the North Sea showed that the probability ranged from 0.3% in the Celtic Sea (Daunt Light Vessel) to 11.9% in the Southern sector of the North Sea (Scalloper Light Vessel). These theoretical calculations confirmed practical experience in that even helicopters ditching intact are very unstable in water and commonly capsize very soon after water landing.

Preventive measures taken which encompass the whole flight operation from training to strap-in to take-off and landing can reduce the fatalities for the typical scenario of a helicopter ditching into water. These are discussed below under six separate headings: 1) pre-flight briefing, 2) in-flight preparation, 3) the unsurvivable accident, 4) the survivable accident, 5) equipment design and improvements, and 6) post-escape. Reference is made when possible to an accident narrative to help illustrate a point. Chapter 3 discusses a formal course training plan for a helicopter ditching course which reviews the six headings.

2.2 Pre-Flight Briefings

Before strapping into a helicopter, and certainly before take-off, it is important that the aircrew and passengers understand the hazards of over water operation and the remedies for survival. A good pre-flight briefing can mean the difference between survival and death. The following accident illustrates this point; no pre-flight briefing was given and the pilot was not even aware of the existence of the survival equipment on board!

> The civilian pilot of a Canadian registered Bell 206 helicopter and two passengers were on a VFR flight. As the helicopter neared the harbour, the visibility reduced in fog. The pilot, in order to remain in VFR, flew at an airspeed of 10 to 20 mph,

75 to 100 feet from the shoreline and 30 feet above the water. Suddenly, the pilot lost visual contact with the shore and all visual references. He was unable to maintain control of the helicopter, and it struck the water and rolled upside down. The pilot and passengers exited the helicopter and climbed on to the inverted wreck. Two passengers were wearing immersion suits which contained flotation devices. One of them was able to swim to shore and then pull the helicopter in close to shore. The pilot was not wearing an immersion suit and suffered from hypothermia and shock. The helicopter emergency locator transmitter was rendered inoperative when it was immersed in the cold water. The survivors were rescued the following day by a local hunter. The pilot stated that he had not known about the existence of immersion suits before seeing his passengers' suits on this flight. He was not wearing a life vest, yet these were stored in the rear cabin section!

Space does not allow for a very comprehensive review; nevertheless, the following factors must be considered. Crew and passengers must be made fully aware that a system or mechanical failure, is potentially always a hazard during a helicopter operation with or without fire. If any problems are going to occur, they tend to do so during the critical phases of flight (i.e. approach, missed approach, transit or the hover). Therefore, the passengers must be prepared to be particularly attentive to in-flight directions at these times. A classic example of this occurred when

a Wessex 60 ditched in the North Sea after both engines stopped in rapid succession shortly after the helicopter had taken off from a gas platform. A successful alighting was carried out and the fourteen occupants were able to escape unhurt and boarded the liferaft. After some twenty-five minutes they were picked up by a rig support vessel.

The pre-flight briefing should also include a short description of personal and aircraft safety equipment and its use, for example, the requirement for the immersion suit to be done up before ditching, so that it will be waterproof, activation of the life preserver, the method of deploying the liferaft, and the operation of the headset or helmet.

The problems of underwater escape should be described, particularly the fact that water will rush in very rapidly, it will be cold and dark and that disorientation will occur. Survival techniques should be explained, such as adopting a good crash position and not undoing the harness until all motion has stopped. Emergency exits and methods for normal and emergency egress should be discussed to give some indication, especially to passengers who have not had a survival course, of how much force is required to operate emergency release handles, push out windows and open emergency doors.

The passengers must also be briefed that once they have escaped from the helicopter and are floating in the water, they should get out of the water and into a liferaft as soon as possible.

Lastly, and most important, is the requirement for paying attention to aircrew instructions during all phases of a mishap.

Pre-flight briefings vary considerably in quality. They depend on the conscientiousness of the aircrew, their motivation to their service or company and, above all, their professional attitude towards their job.

2.3 In-Flight Preparation

This is where the importance of the pre-flight briefing is paramount. It is the main preparation of the occupants for a ditching possibility because commonly in flight there is little time for more than a few curt orders. Brooks (13) showed in 1984 that of 37 RCAF and CF water accidents (including fixed-wing aircraft) in the previous 20 years,the crew had less than one minute warning that water immersion was imminent in 34 cases (92%) and no practical warning at all(less than 15 seconds) in 29 cases (78%). He also showed that the Sea King Helicopter stood the highest risk for sudden water immersion without prior warning. This lack of warning had contributed to the death of crew members in two Sea King helicopter accidents. A later, more comprehensive study by Brooks (10) for the period 1952-1987, showed that there was less than 15 seconds warning in nine of ten Sea King ditchings, only two to three minutes in the other (tenth).

The results are similar in Anton's review of UK Registered helicopter ditchings in the North Sea from January 1970 to November 1983 (8). The warning was less than one minute in two of seven helicopter accidents and less than five minutes in another two cases. This should be emphasized to helicopter crews and be taught in their ditching training. This is the principal reason why a good pre-flight briefing is so essential, namely because it is unlikely that there will be any chance to explain anything during an emergency. For instance, in a recent Puma 330J accident the pilot experienced a tail rotor blade failure returning to shore from a rig off Western Australia (75); following the violent spin after an in-flight emergency in which the pilot lost his headset, it was impossible to brief the passengers for the impending ditching; thus they had not received a pre-flight briefing prior to take-off and they entered the water unprepared.

Once strapped in and in-flight, the objective should be for all crew members to have a thorough knowledge of their personal equipment, be knowledgable of their emergency exits from the aircraft, the operation of their survival equipment and the preparatory procedures for a ditching. Due to the often cramped seating in the helicopter, the passengers must be aware of the difficulty of pulling on a survival suit hood, zipping up a suit and donning a life preserver. As a result, whenever possible, passengers should fly with constant-wear type life preservers and survival suits in the closed-up position. Manufacturers of suits should be encouraged to spend more money and energy on making suits easier and simpler to close in such emergencies. Other simple instructions such as the importance of removing ear plugs before pulling on the hood can make the difference between hearing and not hearing vital aircrew instructions.

In order to obtain this knowledge, it is essential that all professional crew members and all passengers who earn their living offshore receive formal practical training in helicopter underwater escape.

2.4 The Unsurvivable Accident

An observation made by Elliot of Shell (UK) for 12 of the 16 helicopter ditchings in the North Sea was that six (or half) of the ditchings were controlled and six (or the other half) were crashes (50). Furthermore, no fatalities occurred during the controlled ditchings and death on crash impacts accounted for 85% of fatalities.

Some accidents where the helicopter impacts the water at high velocity or disintegrates are virtually unsurvivable. The following narrative describes such an example and further emphasizes the point already discussed, namely that accidents tend to occur during one of the critical phases of flight previously mentioned.

> Following take-off from the ship carrying an external load of a truck, a USN H-53 Sea Stallion helicopter began spinning and rolling to an almost inverted position with extensive breakup and disintegration occurring prior to water impact. The five major sections then sank. All four aircrew died as a result of the mishap. The pilot's seat broke loose on impact but remained in the cockpit. His only major injury was a fractured jaw, but he died of asphyxia due to drowning. The co-pilot's seat also tore loose from its tracks and he was thrown through the windscreen and remained outside the cockpit, still strapped in the seat. He likely died from a combination of drowning and concussion. Both aircrewmen were found outside the fuselage. The crew chief had sustained multiple extreme injuries when thrown from the aircraft and both had died also from a combination of drowning, concussion and injuries.

Fortunately, accidents like this rarely occur, with all crewmembers killed, either in a combination of cabin break-up and impact, or by drowning shortly afterwards (because their injuries preclude them from making an escape). Yet, during this phase of the abandonment, whether the helicopter has remained upright on the surface or has rapidly inverted and sunk, there is still a very high risk of death for individual crew members and passengers.

2.5 The Survivable Accident

A rapidly sinking helicopter is particularly perilous; the factors that contribute to the hazard are discussed next.

2.5.1 Sudden Immersion and Inversion

As stated above, aircrew and passengers usually receive little or no warning of a impending crash (8, 18, 20). A ditched helicopter often rapidly sinks (8, 60, 63, 65, 77, 78) and the immersion occurs after an in-flight emergency during one of the critical phases of the flight. The following accident is typical of sudden immersion:

> A USN H-46 Sea Knight impacted the water after take-off from the ship. The helicopter was noted to never gain more than about 90 feet of altitude. It made an essentially wings-level descent into the water. The entire flight lasted but twelve seconds. The helicopter sank almost immediately, rolling to port as it did. The pilot, crew chief and 13 passengers died. The co-pilot and one passenger suffered major injuries and the remaining two passengers no injuries. Impact forces ripped the cockpit section of the aircraft from the rest of the aircraft. The co-pilot, still strapped in his seat, was thrown/carried to just aft of the aircraft as it came to rest in approximately 53 feet of water. The co-pilot's seat slid from its rails, carrying him free of the aircraft structure. He inflated his life preserver and was carried to the surface. The survivors were rapidly retrieved from the water by a rescue boat.

This tragic accident clearly points out the necessity for a pre-flight briefing, for the crew and passengers to be aware of the possibility of sudden water immersion due to an inflight emergency during the critical phases of flight, and for all aircrew to be trained for underwater escape. It is also a typical example in which the forces involved in the ditching can literally split open the cabin and throw out the occupants (Figure 3).

2.5.2. Injury

In 1984, the British review of helicopter airworthiness (59) noted the fact that it was generally agreed among designers and operators that when helicopters crash they cause, in many cases, unavoidable injuries and often fatalities to the passengers and crew. However, lack of seat integrity, adequate seat restraint systems, and crashworthy cabin structures contribute to these injuries and fatalities. Methods to delethalize the cabins have been slowly applied to operational aircraft. The following accident is a typical case.

> A USN UH-1 Huey was conducting a transit from ship to shore when the aircrew heard a loud grinding/whirring noise in the transmission. The pilot elected to continue to the shore to land. Less than one minute from the intended emergency landing site, at 40-50 feet and 70 knots, complete loss of engine drive occurred. The helicopter impacted the sea and sank quickly in 30 feet of water. The pilot was knocked unconscious and subsequently drowned. The other three crew survived. The pilot's body was found tightly strapped in the cockpit. His visor was missing and his helmet had a deep abrasion on the right forward windshield quadrant corresponding to the autopsy evidence of a blow to the head in that area sufficient to cause unconsciousness. The co-pilot was rendered unconscious at impact. After impact his next awareness was that the cockpit was entirely under water. "Something was on top of me and I couldn't reach my seat belt release. Got right hand under whatever it was and pulled the release. Felt for the door, it wasn't there! Had to slide out of cockpit. Got hung up on something and I seemed attached to my survival vest. It was dark and I only saw jagged metal in front of me. Looked up, saw light, swallowed water, thought I wouldn't last much longer. Got free, pulled toggles and floated to surface. Saw SAR helicopter. Pulled ring on day smoke flare, failed to ignite". At time of impact, the crew chief was securely strapped in. He placed his head in his lap and braced for impact. He was thrown forward into the hoist directly in front of him and temporarily rendered unconscious. On recovery he found that he was totally underwater with his right foot pinned under something. "Pulled about 15 times." Swallowing water "Thought I was gone". He gave one last try, his foot came loose and he surfaced. The second crewman had the door open prior to impact. He noted that the helicopter filled with water fast. He had difficulty releasing his seat belt because the helicopter rolled right, and he went out the left side. His helmet struck on something. He took it off and saw more clearly. He surfaced first, then saw co-pilot and crew chief come to surface.

Again, this accident points out the importance of training for underwater escape. The co-pilot may well not have survived had he not had the underwater escape course. It also illustrates the typical problems of equipment snagging during escape. The problem is still present - in the USN latest figures for 1987, there were three cases in which crewmen were hampered by equipment during escape from an H-46 Sea Knight and fou cases in which crew equipment snagged something during escape (two in an H-1, and one each in an H-3 and an H-46).

The importance of designing good restraint systems for crashworthy seats and a cabin compartment devoid of jagged edges on which clothing or equipment can snagged must be re-emphasized. Shanahan (67) separates injuries into two categories - <u>acceleration injuries</u> and <u>contact injuries</u>. Acceleration injuries are those injuries which often occur some distance from the area of application. The injuries are due to the body's inertial response to the acceleration. A typical example is rupture of the aorta following a high sink rate crash. In this case the application of force occurs through the individual's thighs, buttocks and back in contact with the seat and the injury is due to the shearing forces acceleration of the body. Contact injuries occur when a localised portion of the body comes into contact with a surface in such a manner that injury occurs at the site of the contact. A typical example is a skull fracture as a result of the head striking a bulkhead. Contact injuries may however also produce acceleration injuries at a site distant from the point of contact.

It is important to make a distinction between the two types of injury because prevention involves different strategies. Acceleration injuries are prevented by attenuating the energy of a crash before it can be transmitted to the individual (i.e. energy-attenuating landing gear and seats). Contact injuries are prevented by attempting to stop contact between an individual and a potentially injurious object (i.e. good restraint to prevent flailing of head, body and limbs plus padding of structures that cannot be moved).

Shanahan has demonstrated that contact injuries are about five times more common than acceleration injuries in helicopter accidents, and that they are preventable. Yet military agencies and civilian operators have done little to insist that manufacturers incorporate crashworthy technology into their aircraft.

2.5.3. <u>In-Rushing Water</u>

In-rushing cold water is an extremely serious problem. In 1973, Rice and Greear (60) reported that it was the most frequent problem confronting survivors. They recorded that 43 survivors had experienced in-rushing water alone, 34 times in conjunction with difficulty in reaching the hatch, 26 times with confusion and disorientation and 12 times with darkness. More recently, in-rushing water was reported by the USN Safety Centre to be a problem in 57 cases of helicopter crews ditching in water during the years 1983 through 1986. Thornton's yet unpublished USN figures for 1987 describe an additional nine cases (56). One pilot that survived a ditching graphically described the sensation to be "like being hit in the chest by a fire hose".

> Following a tail rotor failure, a USN H3 Sea King helicopter impacted the water and commenced rolling left. Both crewmen egressed through the cargo door before the aircraft became completely inverted. <u>Both had difficulty due to in-rushing water.</u>

Figure 3. Typical helicopter accident in which cabin has split open on water impact.

The pilot unbuckled, reached for the window emergency release handle and was unable to exit through the open window, and became stuck 1/3 way through. He pulled himself back in the helicopter, rotated body 50° and pushed his body through the window.

In-rushing water has four serious effects, all of which may lead to drowning. The first effect is panic since the person is exposed to potential drowning; the second is uncontrolled hyperventilation and reduction in breath-holding ability (32, 33, 38, 45, 46, 58, 69); and the third, is buffetting in the seat which may lead to intense disorientation. A fourth effect is an exaggeration of the first two - that of immersion in cold water. If the water is below 10 C and the survivor is not wearing a protective suit, the chances of drowning is enhanced through a combination of events, panic, hyperventilation, reduced breath-holding ability, and the development of a cardiac arrest or arrythmia.

Panic can only be prevented by good, repeated, realistic training. The reduction in breath-holding ability can be combatted by supplying supplementary air. Arrythmia can be prevented by providing good, comfortable, practical dry immersion suits. Disorientation can be ameliorated by having had practical escape training in an underwater escape trainer and by adopting a good crash position.

2.5.4. Disorientation

The rotation of the body underwater and loss of gravitational references makes disorientation inevitable for survivors prior to escape from an inverted sunken helicopter. In conjunction with darkness, which contributes to disorientation, it is the second biggest problem, after in-rushing water. Confusion/panic/disorientation was reported in three cases for 1987 USN accidents and darkness was a problem in ten accidents.

The crew of a USN H-3 Sea King helicopter were conducting an automatic coupled approach to a sonar hover when the master caution light was illuminated, followed by a steady transmission oil press caution light. The helicopter made an emergency water landing, rolled, inverted and sank. Upon hitting water, the pilot released his lap belt and in-rushing water pushed him from his seat. He immediately became disoriented. He felt a seat, groped for a window, and exited throught the co-pilot's window. The co-pilot had released his lap belt and exited feet first through his sliding window after removing his helmet. After all forward motion ceased, the crewman released himself and exited through the left sonar window just as the helicopter began to roll. The report noted that the pilot and co-pilot had not had helicopter underwater escape training and also that the crewmen were treated for cold water immersion.

Only those who have experienced disorientation in a helicopter underwater trainer understand the problem and how to deal with it. Even experienced professional divers are surprised at the profound disorientation experienced when they first attempt the trainer. It cannot be taught entirely at a desk in a classroom; it must be practically demonstrated in a trainer. Ryack et al (64) noted that, in spite of their lengthy experience, 16 of 24 divers testing escape hatch illumination became seriously disoriented and needed assistance.

Helicopter underwater escape should be practically taught to all professional aircrew and passengers who must routinely travel over water. The benefits of training are clearly shown by Ryack et al (63) from the statistics of the US Navy Safety Centre from January 1969 to February 1975. During that time 424 men were involved in helicopter crashes into water. Less than 8% (13) of those who had received underwater escape training (170) died in the crashes, compared to more than 20% (54) who had not received training (254). The importance of adopting a good crash position is also essential and will be discussed in the next section.

2.5.5. Crash Position

(i) General

In survivable accidents, the most common reason why personnel die is injury before escape (60,67). Death is principally from contact injuries rather than acceleration injuries by a ratio of 5:1. The adoption of a good crash position can increase the survival rate in five ways:

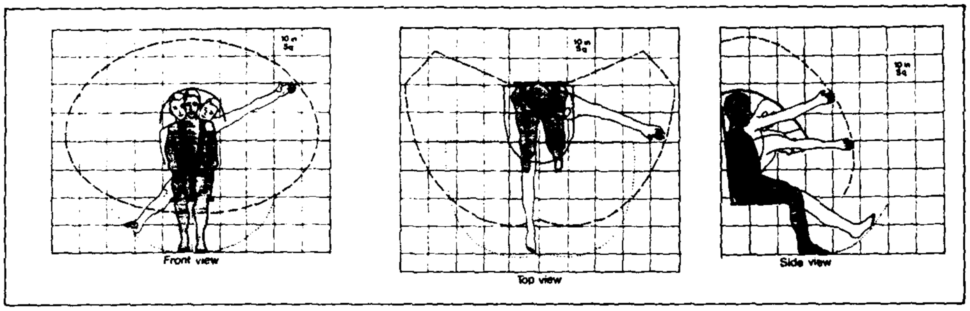
- by reducing the strike envelope of the arms, legs and head on the cabin contents. (The potential strike envelope for personnel with five point restraint and lap straps only is graphically illustrated in Figures 4 and 5 to demonstrate the seriousness of the problem (74));

- by stabilizing the survivor in the seat and minimizing the disorientation during and immediately postcrash, particularly during an accident with smoke and/or fire, or with sudden in-rushing water or darkness in sinking helicopters;

- specifically for underwater escape, by minimizing the profile of the body to the inrushing water, which further increases disorientation;

- by presenting a smaller human target area to flying debris;

Figure 4. Potential strike envelope for personnel using a five-point harness.
(Courtesy U.S. Army Research and Technology Laboratory, Fort Eustis, Virginia).



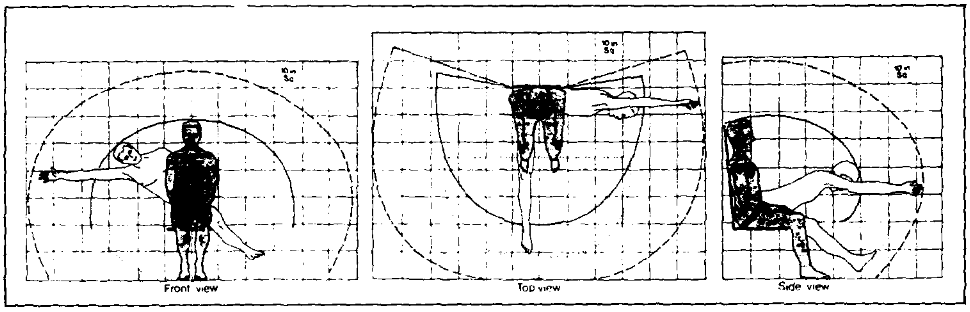


Figure 5. Potential strike envelope for personnel using a lap strap only.
(Courtesy U.S. Army Research and Technology Laboratory, Fort Eustis, Virginia).

- by providing the survivor with a good physical reference from which to rapidly re-orient and rationally consider what escape path to take.

Special considerations apply to helicopter crash positions compared to fixed-wing aircraft crash positions. A general review of the subject is well documented in the AGARD Conference Proceedings on Operational Helicopter Aviation Medicine in 1978 (1). The crash dynamics for helicopters, particularly ditching in water, may be different than for fixed-wing aircraft. Helicopters tend to crash vertically or, under autorotation conditions, at more acute angles to the surface of the water or ground. The vertical component of the crash forces can be much greater than forward component. Disorientation is inevitable if the helicopter sinks and rolls and, as previously mentioned, is intensified by in-rushing water, which destabilizes the whole body in the seat.

Shanahan (67) describes two types of injury - acceleration and contact. To prevent acceleration injuries, a method of attenuating the energy of a crash before it can be transmitted to the individual must be devised. Such devices as energy attenuating landing gear and seats can achieve this, as well as the controlled deformation of airframe structures; however as previously mentioned, little of this technology has been applied to helicopters presently flying offshore. Although there were no water accidents in his study, pertinent findings to this review are that 88% of all Army Class A helicopter accidents were considered survivable, while 32% of the fatalities and 96% of the disabling injuries occurred in survivable crashes. Better restraint removal of potentially injurious objects and adoption of a good low profile crash position are required to prevent contact injuries.

Most pilot seats are fitted with 4-point harnesses with or without headrests, but crewmen and passengers have simple lap straps, commonly with no headrests at all. Seating in helicopters is not always conventionally arranged in an all forward-facing configuration. Side-facing seats are structurally weaker because of asymetrical loading. The preferred safe passenger seat position is rear-facing, followed by forward-facing and lastly, side-facing. Seats are often fitted in an ad hoc fashion to carry out the operational requirement of accepting cargo, fuel cells, and passengers in the same helicopter. With weight and space limitations, they are often fitted in a somewhat jig-saw fashion around these items. Before crash position advice can be given, each different aircrew and passenger position, with its type of harness and presence or absence of headrest, must be considered separately.

(ii) Pilots

As a general rule for pilots, it is essential in any accident scenario that the the harness is tight and locked and that the buttocks are tightly pressed into the back of the seat. It is vital to reduce the strike envelope of the body extremities on the dashboard. The style of seat and whether or not the pilot is in control will dictate what position to adopt.

(iii) Pilot in Control - Headrest Fitted (Figure 6A)

It is unlikely that the pilot will be able to let go voluntarily of cyclic and collective controls or take his feet off the rudder pedals before impact. In fact, it is likely that he/she will grip them even harder during the last vital milliseconds before impact. Most training teaches that the pilot in control must continue flying the helicopter into the ground or water until it has stopped completely. Because the pilot will be in firm physical contact with the controls the crash forces will be transmitted through the limbs, resulting in possible fractures. Depending on the severity of forces involved, the limbs may flail, but there is little that can be done to prevent this. The head, however, is the most critical area to protect from the instrument panel. To reduce the strike envelope, it is recommended that pilots tuck their head and neck tightly into the root of their neck and chest, and force their head back into the headrest. If they have the opportunity at the last moment to let go of the controls, then they should follow the next procedure as described for the pilot not in control.

(iv) Pilot Not in Control - Headrest Fitted (Figure 6B)

The pilot should withdraw his feet from the pedals and place them firmly on the floor, but not wrapped around either front corner of the seat and squeeze the knees firmly together so that the legs form a triangulated shape, with the heels are on the cabin floor comfortably about 10-15 centimetres (4-6 inches) apart. This reduces the human profile and stabilizes the body against in-rushing water. The head should be again tucked firmly into the root of the neck and forced back into the headrest. To avoid the limbs flailing and striking the dashboard and/or extraneous cabin controls, the arms should be folded across each other in scissor fashion and the hands should grasp the opposite coat/coverall collar at the crown of the shoulder and, if possible, the shoulder harness. This will provide support for the chin and protection for the face.

(v) Pilot in Control - No Headrest (Figure 6C)

There is no head support and it is likely that the head and neck will be injured by both acceleration and by direct impact. The only advice that can be given under these circumstances is that, if possible, the head should be tucked as tightly as possible into the root of the neck. If the hands can be released from the controls at the last second before impact, then the head should be protected in the same manner described below for the case of the pilot with no headrest and not in control. Lastly, again if possible, the feet should be withdrawn from the pedals and put on the floor in a triangulated position.

(vi) Pilot Not in Control - No Headrest (Figure 6D)

The crash position of the feet and body should be exactly the same as in the situation with a headrest fitted. Without a headrest, however, the head and face are to the hand and elbow positioning. If it is at all possible, the hands should grip the collar of the flight coverall as far back as possible at about the point where the shoulder harness crosses the shoulder. This then protects the face in the crook of the elbow.

(vii) Crewmen and Passengers with Lap Strap Only (Figure 7)

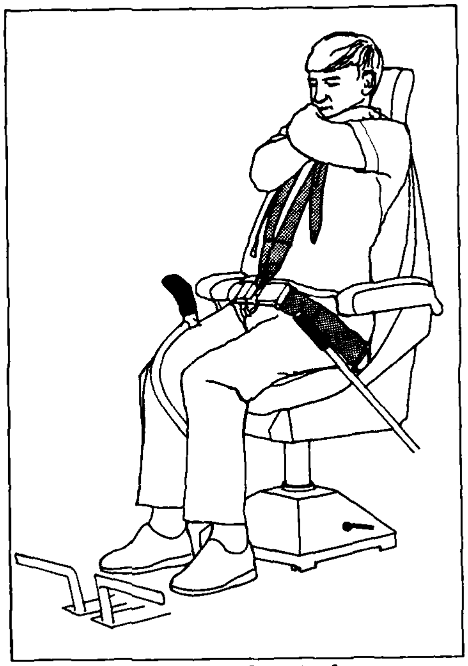
Traditionally, there have been five types of crash positions advocated for passengers in fixed-wing aircraft wearing a lap strap. These positions have been transferred directly and adopted in the helicopter passenger scenario with little consideration for the fact that the majority of impacts have strong vertical force components with a high chance of contact injuries. No consideration been given to the profound disorientation effects of sudden immersion and inversion and the effects of in-rushing water. The only method to enhance escape is to adopt a crash position in which one hand always grips a part of the seat. This is called the manual physical reference point; only with this reference point will it be possible for the survivor to form a mental image of which way to proceed to an escape hatch after the accident. (Even this is not fool-proof if the fuselage has been seriously deranged.)

The following positions do not have manual physical reference points and are NOT recommended for use by helicopter personnel in seats with a lap strap prior to ditching into water. They are described and criticized as follows:

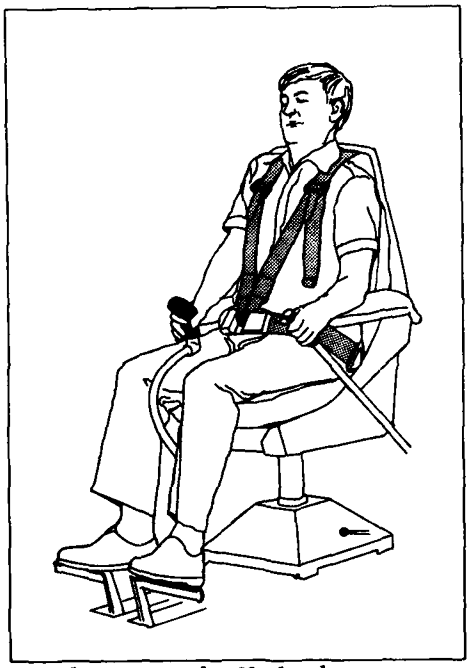
Position 1 (Figure 7A)
The crossed hands/wrists are placed on the top edge of the seat in front and the head is buried into the wrists. The buttocks are pressed into the back of the seat and the knees and feet pressed firmly together on the floor. Unfortunately, this position is not satisfactory for various reasons. First, the strike envelope is extremely large. Second, the large body and limb

Figure 6. Recommended positions for pilots ditching helicopters in water using a 4 or 5 point restraint harness.

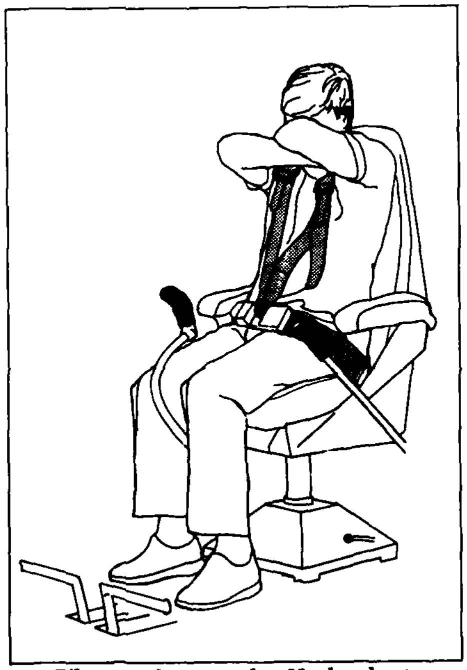
A. Pilot in control - Headrest



B. Pilot not in control - Headrest



C. Pilot in control - No headrest



D. Pilot not in control - No headrest

surface area is prone to flail due to crash forces and in-rushing water, which in turn makes disorientation worse. Whole body and limb stability would be enhanced if the legs were positioned in the lower-body triangulated position described for pilots. Third, the seat in front is likely to fold forward during a vertical impact which will cause the head to strike either the base of that seat or the survivor's own knees. And fourth, after the impact there is no manual physical reference point with the seat for re-orientation to assist in determining direction of escape.

Position 2 (Figure 7B)
The hands are folded across the chest grasping the front and/or sides of opposite knees, the buttocks are pressed firmly into the back of the seat, the back is flexed forwards and the head flexed forwards and buried into the crook of both elbows. The knees are placed together, and the feet are pressed firmly together on the floor. Although better than Position 1, there are still three important criticisms - flailing in the seat is likely due to inrushing water because of the lack of firm fixation to seat to enhance the stability, the legs are not placed in the triangulated position, and there is no manual physical reference point for re-orientation.

Position 3 (Figure 7C)
The third position is a variation of Position 2. Instead of folded hands grasping the front and/or sides of the opposite knee, they grasp the outside of opposite thighs to keep the knees closed together. This is considered an improvement because the hands are in a more natural position and the legs naturally fall into the triangulated position. However, the position is still not satisfactory because there is a still no fixation to the seat and no manual physical reference; thus the occupant can still flail and have difficulty with re-orientation.

Position 4 (Figure 7D)
The forearms are crossed at the wrists, and the elbow are placed on either knee. The buttocks are pressed firmly into the back of the seat and the back is flexed so that the face is protected in the palms of the hands. The legs an knees are placed together, with the feet pressed firmly on the floor. This is a poor position because it is extremely vulnerable to head injury, because there is a large strike envelope. The seat occupant is extremely unstable and susceptible to the effects of in-rushing water because of the large profile. There is no manual physical reference to the seat for re-orientation. And finally, the feet are not in a good stable triangular position.

Position 5 (Figure 7E)
This position is the one advocated for rearward facing passengers. The person sits bolt-upright in the seat, buttocks firmly in the back of the seat, head pushed into the back of the seat, knees together, heels together and feet pressed firmly on the floor. The hands are held together in front of the pubic bone (Figure 7E). This position assumes that the majority of the force exerted on the passenger will be forward, whereas it is more likely to be vertical. This again is a poor position for under such conditions there is no protection for the face and the body presents a large strike area and will likely jack-knife on to the knees of the passenger in the facing seat. Resulting spinal, cranial and facial injuries could be fatal. It is an unstable position

(viii) Recommended Position for All Personnel with Lapstraps (Figure 8A and 8B).

This position should should be able to be maintained in at least a 4G impact and protects against the effects of in-rushing water. The recommended position to be adopted by all personel in forward, rearward,or sideways-facing seats is as follows:

(a) The lap strap should be cinched up tight and any excess length of strap distal to the buckle should be tucked inside the strap so that it does not float across the release buckle when underwater and obstruct release (commonly noted during underwater escape training).

(b) The body profile and strike envelope should be reduced to a minimum by pushing the buttocks tightly into the back of the seat and bending forwards as tightly as possible so that the torso lies on top of the thighs and the head presses tightly on the knees.

(c) The knees should be pressed and held firmly together by wrapping one arm underneath and around the thigh, gripping with the hand of that arm the underside of the opposite thigh or trouser leg. This hand is the first one to be released after the accident. The other hand should grip the edge of the seat at the mid-thigh level, close to the trouser seam. This is the hand that maintains stability in the seat and the one manual reference point for re-orientation once all motion and bubbles have stopped. This hand is to be released last before finally leaving the seat to escape. The hand that holds the seat should be the farthest from the escape exit, i.e., if the right hand is cl sest to the exit, then the left hand should hold the seat and the right arm and hand should hold the knees together. Once the turbulence has stopped, the right hand feels for the exit while the left hand still maintains seat reference.

Figure 7. Five crash positions NOT advised for helicopter personnel using lap straps prior to ditching in water.

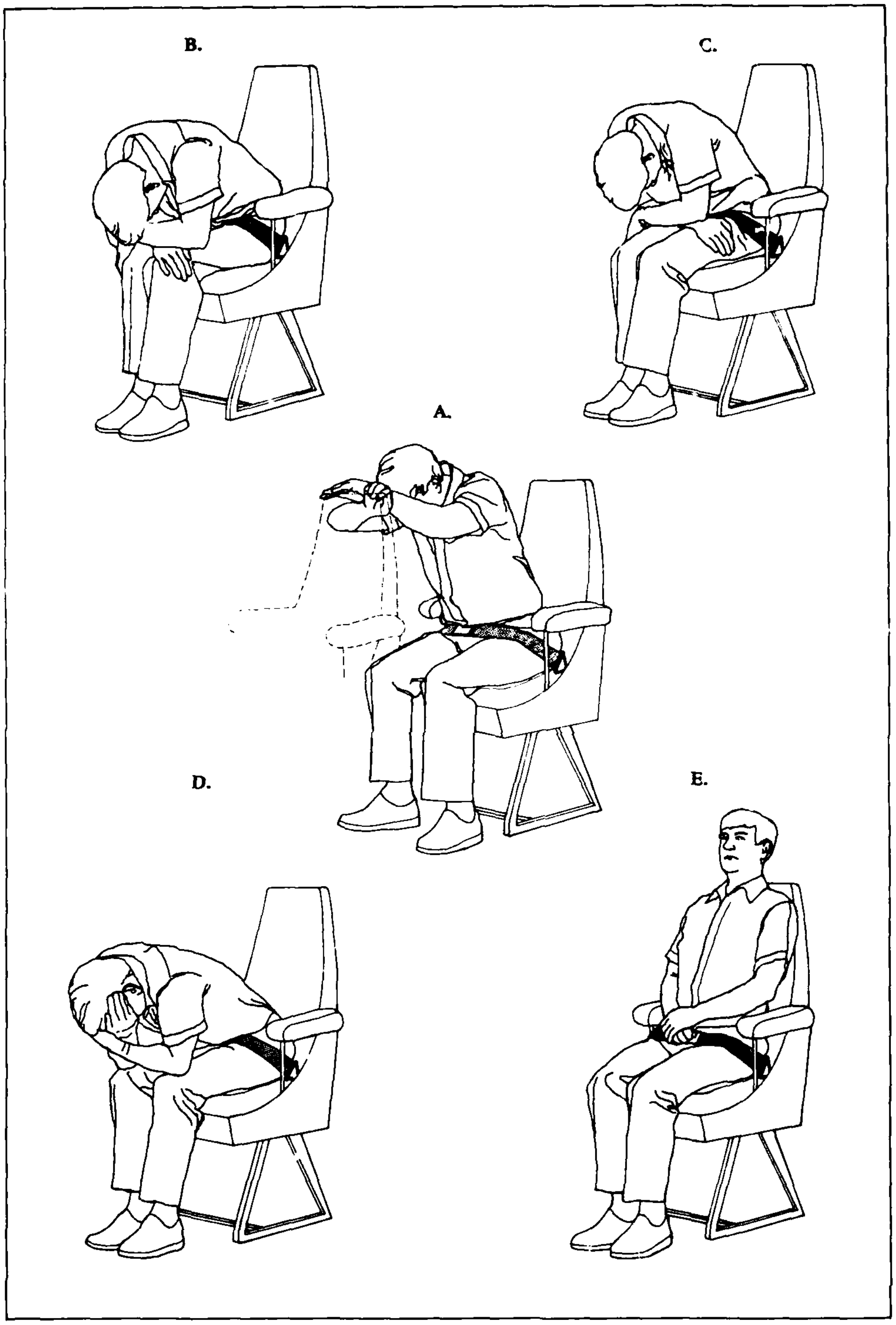
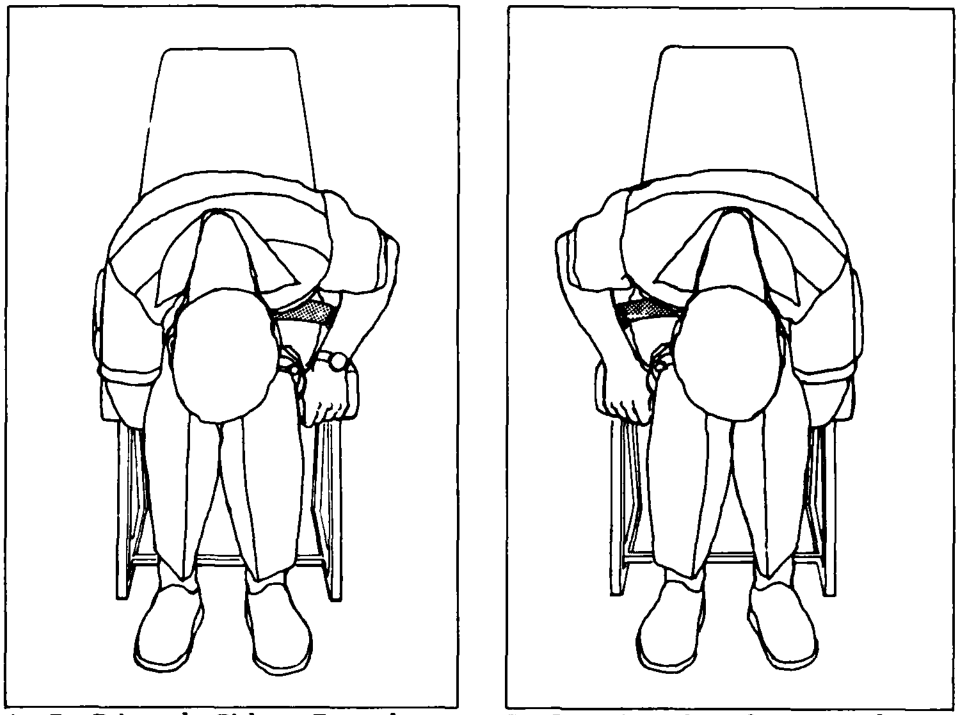


Figure 8. Recommended crash position for all personnel (crew and passengers) using lap straps.



A. For Exit to the Right or Forwards **B. For Exit to the Left or Forwards**

(d) The feet should be placed firmly on the floor, the heels comfortably approximately 4-6 inches apart. With the knees together, the legs adopt a slightly triangular position.

ix) Alternative Position for Crewman or Passengers with Space or Anatomical Limitations (Figure 9)

Those passengers wearing lap straps, whose anatomical shapes donot allow them to adopt the standard position and by those passengers in a small cramped cabin where there is not enough room to do so, should adopt the following position. The leg position should remain the same triangulated position as in the standard position viii(d). One hand must grip the edge of the seat to maintain a reference point, as in viii(c). The other hand should be folded across the chest and grip the opposite coat collar beneath the ear, and the head should be buried as tightly as possible into the crook of the elbow. The spine should be bent forward to bring the face as close to the knees as is practical. The hand positions are interchangeable depending on direction of escape.

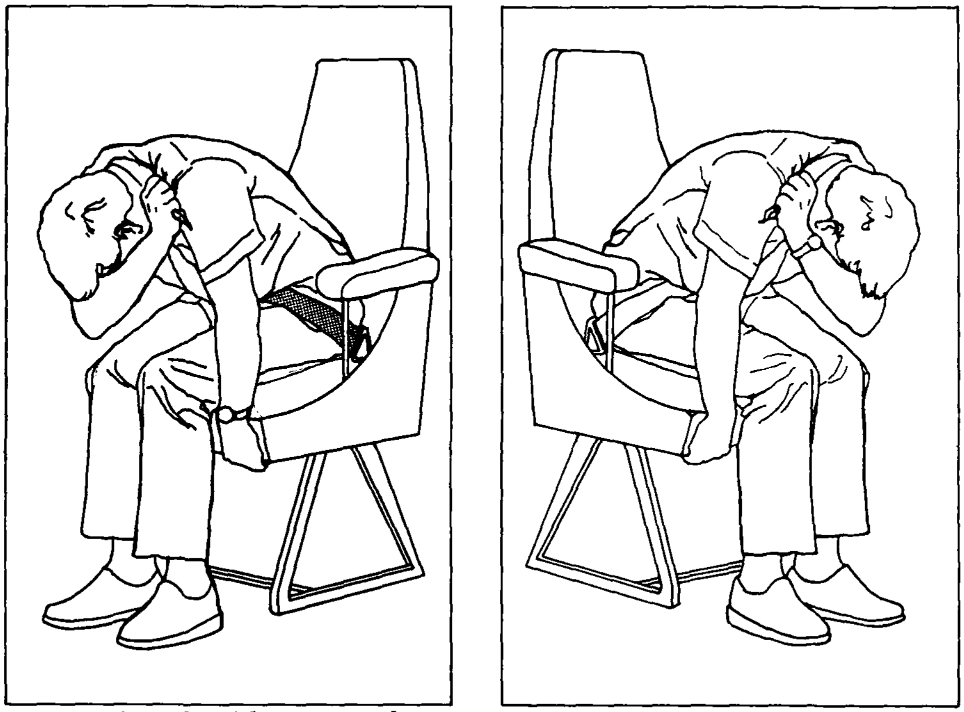
(x) Unrestrained Crewman

Those unrestrained or on a long tethered harness prior to impact, should if at all possible strap into the nearest seat and assume the position as recommended in 2.5.5. (viii) above. Otherwise they should immediately lie face down flat on the floor with their heads buried in the crook of their arms. In fact this is exactly what one USN crewman did recently and he was the only one, out of four crew, who did not suffer a compression fracture of the spine.

2.5.6. Visibility - Effects of Darkness

Darkness compounds disorientation and has significant effect on survival rates. As mentioned previously, in conjunction with in-rushing water, Rice and Greear (60) reported darkness to be a problem 12 times in 78 helicopter accidents between 1969 and 1972. The USN Safety Centre reported that cumulative survival rates for day and night helicopter water accidents from 1978 to 1984 were, respectively 79% and 62%. And

Figure 9. Recommended alternative crash position for all those who cannot adopt the standard position.



A. For Exit to the Right or Forwards **B. For Exit to the Left or Forwards**

for the year 1987, the USN reported darkness to be a serious problem in three H-2 accidents, three H-3 accidents, and four H-46 accidents (18). In 1984, Brooks (17) reported two Canadian Sea King helicopter night accidents, in which only three of eight crew survived, concluding that darkness contributed to the cause of death. The following accident describes the problem of darkness and disorientation.

> Following a system malfunction, a USN H-3 Sea King helicopter, during flight at approximately 150 feet altitude, suddenly departed from controlled flight and impacted water. Despite bright daylight, moderate sea state and low impact forces, all occupants (survivors) of the helicopter *suddenly found themselves disoriented in a very dark-water-filled inverted cabin area*. The pilot was unable to locate the window jettison handle, and in desperation, forced himself through the open pilot sliding window! Although his window jarred free on impact, the co-pilot became disoriented upon egress and swam down for a short time, which led to ingestion of water and fuel. The right-seated crewman found himself unable to exit through the right crewman's window (probably blocked by collapsed sponson or bent rotor blade) and had extreme difficulty locating an alternate exit. He was under water for a considerable length of time, finally exiting from the area of the open cargo door, unsure whether he got out through the door or through a hole in the fuselage. The fact that none of the survivors remembers seeing any of the lost crewmembers after impact further attests to the acute darkness/disorientation problem.

Although training can greatly reduce egress fatalities, it cannot entirely solve the problems of darkness, disorientation, and lack of visibility through bubbles and debris, due to the fact people often will not open their eyes underwater. In the last twenty years, considerable research on underwater lighting has taken place; yet there has been very little determination by operators and helicopter manufacturers to implement the results.

2.5.7. Underwater Lighting

In 1962, the Royal Navy established a requirement to mark the escape hatches of their Wessex and Whirlwind helicopters with lights to facilitate escape at night (27). Initially, continuous tritium-activated gas light sources were considered, but at that time were not considered bright enough for underwater use. Consequently, in 1965, Wessex modification 737 and Whirlwind modification 1742 introduced systems powered by sea water cells. Although these systems supplied ample light, they were found to deteriorate rapidly in service use in the damp salty environment and were costly to replace. Furthermore, it was impossible to test the cells for serviceability and remaining capacity. In 1968 and 1969, with the advent of new technology, the Royal Navy re-evaluated a series of tritium gas sources, which worked on the principle that the gas emitted low energy beta-particles which, in turn, activated a zinc or cadmium phosphor. The colour of the light emitted depended on the phosphor used. Any radiation given off was absorbed in the phosphor and or borosilicate glass which enclosed the complete system. They concluded that one of the tritium-activated green light sources, measuring approximately 1 inch in diameter and producing 6 candelas per square metre, was sufficient to mark each hatch for underwater escape purposes (27). They confirmed this conclusion in the underwater escape trainer at HMS Vernon and in the open ocean. The principal advantages of such lighting were that it was self-contained, easily fitted, and required no complicated installation, power supply, or emergency switches. Once fitted, it provided continuous light, it had a long maintenance-free life, and required no testing, since it could be seen at a glance if it was functioning correctly. The only drawback was that if the source broke, a small quantity of low-dose radioactivity would be released. Nevertheless, these lights were subsequently adopted in Royal Navy helicopters, Canadian Forces Sea King helicopters, and probably military helicopters of other countries. However, it now appears that beta lights (as they are now known) are not as effective as evidenced by the following accident:

> In the hover at 40 feet a Royal Navy Sea King helicopter experienced severe vibration, probably from loss of a main rotor blade, and the aircraft was ditched. The blades struck the water and caused the helicopter to roll inverted and sink rapidly in the 4-8 foot swell. The co-pilot kicked at his window but was disoriented. The observer released his harness too early and was thrown around. The overall comment by the survivors after the escape was that the beta lights were not visible underwater.

In the United States, the first published work on emergency underwater exit lighting was by Clark for the US Coast Guard in 1969 (23). At that time, he tested five devices - one RF-excited fluorescent light from Dymo, two electroluminescent devices from Grimes and a 'Capsul' light from Atkins and Merril, and lastly a new technology chemoluminescent system from the Remington Arms Company. Although no absolute conclusions were made, it appeared that the electroluminescent systems showed the best promise.

Ryack and Luria (43,62,63,64) at the Naval Submarine Medical Research Laboratory continued with studies on the effects of escape hatch lighting. They emphasized the requirement that the lights should be visible underwater at a distance of 12 feet in turbid water at an angle of ± 65° from direct view. They considered three types of lights - tritium, chemoluminescent and electroluminescent. Again the latter was found to be the most promising because the lights were flat and thin and could be contoured into any shape. They were also battery powered and easily waterproofed. Furthermore, the colour was close to the optimum for underwater viewing.

Ryack used a team of professional USN divers to carry out a series of escapes from a simulated Sea King H-3 helicopter hull with and without hatch lighting (64). The escape times were significantly shorter when the hatches were illuminated and longer before the learning effect of the test had been established, (Figure 10). Subjects' responses on the evaluation questionnaires showed strong support for the use of the lights, particularly at night. When asked to evaluate the difficulty of night escape on a scale of 1 (exceptionally easy) to 6 (exceptionally difficult), their mean rating was 1.5 with lights on and 4.6 with lights off. There were six recorded instances in which subjects became disoriented, lost, or entangled, five in the absence of illumination and one with lights. It was concluded that the lights were of demonstrated benefit and should be installed around hatches.

Optical characteristics of the lights were then studied by a team at Groton (68). They stated that the visibility of a light underwater depends primarily on intensity, viewing distance, water turbidity and dark adaptation of the observer. Nomograms were established for estimating the threshold luminance of a light in the water for an observer without a facemask (Figure 11).

Luria et al in 1979 (44) then studied flashing lighting configuration, shape of lights around hatches, printed signs and viewing angle (43,44,63). Two steady lights, a high intensity collimated beam and a chemoluminescent light stick were tested and compared with a large and a small xenon strobe light with a flash rate of 1 flash/s. They showed quite conclusively that flashing lights around hatches were confusing and should not be used. The best configuration was found to be one in which the top and both sides of the hatch were illuminated, in an inverted U pattern (Figure 12). Short wide panels were more visible than long narrow panels of the same total area. It was concluded that, at night, the smallest back-lighted letter readable underwater is 3 inches high, that little information could be printed so that it would be legible

Figure 10. Mean times required to escape from submerged helicopter on three successive days through lighted (O) and unlighted (●) hatches. (24 subjects attempted each escape condition twice).
(Courtesy Ryack, Luria and Smith, USN Submarine Research Laboratory).

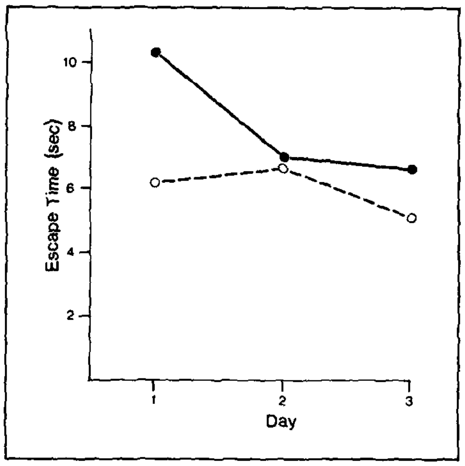


Figure 12. Recommended configuration for lighting around hatches.
(Courtesy Ryack, Luria & Smith, USN Submarine Research Laboratory).

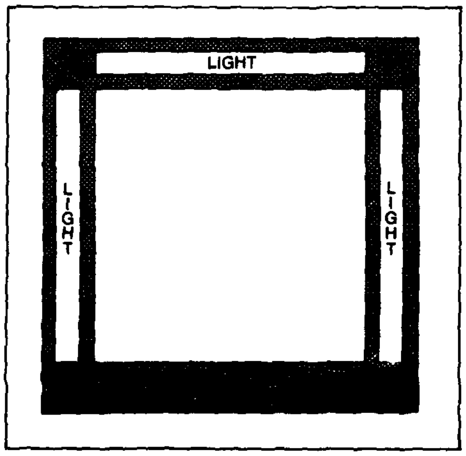


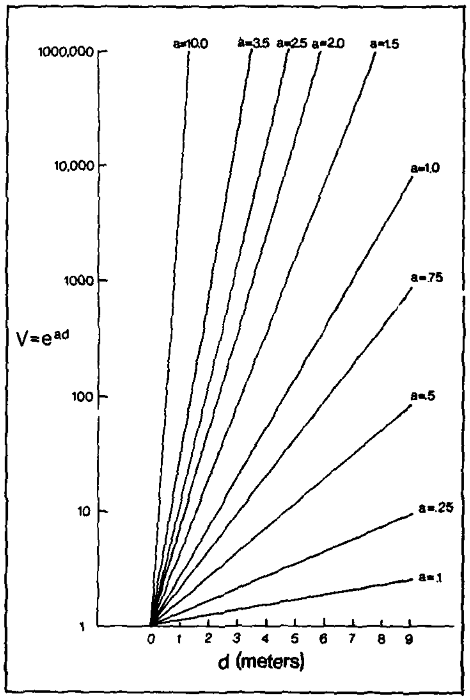
Figure 11. Nomograms for estimating the threshold luminance of a light in the water for an observer without a facemask.

v = degree of transmittance of the light through the water

d = distance the light must travel to the observer

a = turbidity of the water (an "a" of 0.1 indicates very pure water, whereas an "a" of 3.0 is characteristic of turbid harbour water.

(Courtesy Smith & Luria, USN Submarine Research Laboratory).



underwater, and that it was not feasible to use printed instructions underwater. They also found that, as would be expected, more light is required for a less direct viewing angle. In less turbid water, the detection times do not increase very much until the viewing angle is quite oblique (62).

More recently light emitting diodes (LED) have been developed for underwater lighting. LEDs are used in the Helicopter Emergency Egress Lighting system (HEEL) manufactured by H. Koch & Sons in the United States (79) and in two types of EXIS lights that are sold by R.F.D. Limited in the United Kingdom.

Allan et al (4) evaluated such LED devices to compare their underwater detectability under varying conditions of water turbidity, ambient illumination, viewing distance and viewing angle. The most significant findings were, first, that none of the lights could be seen by any subject at 3.1 metres in turbid conditions regardless of ambient illumination, whether viewing was through a simulated face mask or simply immersed. Second, subjects immersed underwater had great difficulty detecting the lights at 1.54 metres viewing distance especially under bright and medium ambient illumination at 60 lux. Even in the dark at 1.54 metres, some subjects failed to detect the light and the mean detection times were considered unacceptably long. The experiment confirmed the usefulness of goggles or face masks and, although the wearing of such items would not change the ability to see the LEDs at 3.1 metres, it would make a dramatic difference at 1.54 metres. Allan et al cautioned that designers of helicopter underwater escape lighting systems should understand that visibility over distances of greater than 1.5 metres is very unreliable and more than likely would be obscured due to luggage, debris, bubbles and even other passengers escaping. He recommended as the best form of lighting an illuminated guide bar which, by flashing, would direct escapees to the exit. A prototype has recently undergone preliminary evaluation at the RAF Institute of Aviation Medicine and has shown great promise (3). Results showed that the escape times were reduced when the bar was operational. All the subjects considered that it made escape much easier, particularly in turbid water.

2.5.8. Optimum Colors for Marking Hatches, Etc.

What are the best colors for marking escape hatches and escape routes? Work by Kinney et al (39) in 1967 determined which colors are most visible underwater, emphasizing that it was much more complex than making the same determination in air.

Using previous data from Oster (47), Hulbert (34,35) and Jerlov (37), they concluded that fluorescent orange is the most visible colour for rivers, harbours, and other turbid bodies of water. Non-fluorescent colours of good visibility are white, yellow, orange and red. For coastal waters of mediocre clarity, fluorescent green and fluorescent orange are superior and white, yellow, and orange are the best non-fluorescent colours. For clear water, fluorescent greens and white are the best choices. As the clarity of water increases, with a consequent increase in viewing distance, the most visible colour will change from yellow-green to green to blue-green. Fluorescent materials are superior to non-fluorescent materials of the same colour in all bodies of water. White is the best non-fluorescent material in all bodies of water. The most difficult colours to see at the limits of visibility under natural illumination and a water background are grey and black. Other colours that have poor visibility are those whose major spectral components are absorbed by the water (i.e., orange and red in clear water and blue and green in murky water). Only a limited number of colours will not be confused with other colours underwater. To avoid confusion, if absolute identification is important, the following color combinations are suggested for escape hatches: green, orange and black; blue, green, orange and black in clear water; and green, yellow, red and black in murky water.

2.5.9. Visibility Without a Facemask

Lauria and Kinney made the observation (42) that almost no attention has been paid to the measurement of the visual processes of divers in water without facemasks, yet there have been many occasions in which an escaping submariner or helicopter crewman ditching in water needed to see underwater in order to be able to escape. They concluded that only stereoacuity is markedly degraded underwater and that, despite a great decrease in range of visibility, distance estimates are reasonably accurate. Size estimation tended to be too small, and those subjects with refractive errors did not appear to be more hampered than those with normal vision.

Allen and Ward in the United Kingdom (6) and Brooks in Canada (11) quite independently observed that underwater vision during simulated escape is greatly aided by wearing a simple pair of swimming goggles and that these should be included as part of the safety equipment provided to everyone (crew and passengers alike) in helicopters flying over water. Personal observation over a span of 22 years of occupational submarine and diving medicine has shown, perhaps not surprisingly, that many people are terrified to open their eyes underwater. It is presumed that a significant number of fatalities have occurred because the survivors have literally been too frightened to open their eyes underwater and therefore could not make the appropriate escape response.

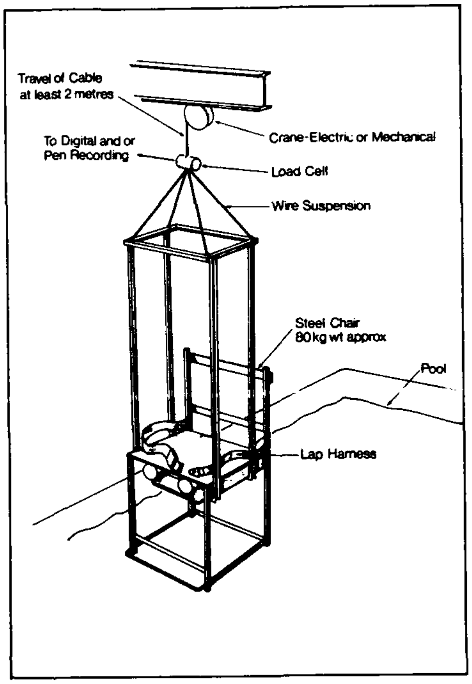
Practical training, of course, can only solve some of this problem. In the next generation of helicopters, this fact should be taken into consideration. Manufacturers and designers must be encouraged to develop escape routes which are achievable in complete darkness, irrespective of whether underwater lighting is available; in effect, it might be like an underwater braille system. Some years ago, an attempt to do this was made by the Royal Navy in their Wessex helicopter. A series of cones were fitted on a bar which lead to the escape hatch. No report could be found as to their usefulness in aiding underwater escape. The French Navy have a similar idea in their Alouette II helicopters; there is a tape with plastic knobs on it to guide personnel in the back of the helicopter to the escape hatch.

2.5.10 Excess Buoyancy

Added to the effects of in-rushing water, disorientation, and darkness are the effects of buoyancy once the harness buckle is released. Except for those who are very agile, comfortable underwater and practiced at escape, the buoyancy may indeed be of such a high value that it slows down or even prevents the survivor making an escape. The following accident is such a case:

> The Tactical Observer of a Canadian CH124 Sea King helicopter was standing in the stern of the helicopter at 50 feet in the hover, when it suddenly lost power, plunged into the water, inverted and rapidly sank. Due to the fact that his regular constant wear immersion suit was under repair, he was wearing a very bulky, loose fitting quick don suit which contained large volumes of trapped air. Completely disoriented and pinned to the floor of the helicopter by the additional buoyancy, he described floating helplessly around like a zeppelin within the cabin. He could not see the beta light to guide him to an escape hatch. Only by the greatest stroke of luck, when he thought he had met his demise, did he spot a glimmer of light and managed to haul himself out through an escape window (66).

Figure 13. Simple chair designed to measure the buoyancy of immersion suits worn by humans when completely immersed in water.
(Courtesy Canadian General Standards Board. 65.17-M86)



In 1982, the Ocean Ranger oil rig disaster occurred off the coast of Newfoundland. As a result, the Canadian General Standards Board (CGSB) identified a requirement to establish a helicopter passenger immersion suit standard. One question asked was how much inherent buoyancy could an immersion suit have without impairing escape from an inverted helicopter? At that time, a literature search by Brooks failed to identify any previous work in this area.

In 1984, to establish a preliminary standard, Brooks et al (17) conducted two sets of experiments simulating a helicopter escape, first in a closed flooded diving chamber using clearance divers, and second in an open pool using naive swimmers. They concluded that the shell of the immersion suit alone should not add more than 89 Newtons (N) or 20 lbs buoyancy, and it was recommended that this figure be confirmed in the dynamic situation using a Helicopter Underwater Escape Trainer (HUET).

The original experiments by Brooks et al (17) indicated that the maximum inherent buoyancy for the total suit system must be less than 177 Newtons (40 lbs). The definition of inherent buoyancy of a suit system is the total amount of buoyancy of the user of the suit and liner materials, and of any trapped air (between the skin, linings and outershell and in the suit pockets), after total immersion in a seated position for 15 seconds. It was recommended that the suit shell buoyancy not exceed 89 Newtons (20 lb) since the insulating layer, shirt, trousers, liner, etc., would add an estimated 44-89 Newtons (10 - 20 lb) to this value. The underclothing worn would depend upon weather conditions and personal preference.

It then became apparent that measuring the buoyancy of just the shell of a suit did not take into account the true dynamic effects of trapped air in the whole suit system during a ditching. Therefore, the Canadian Offshore Research and Development Group of Nova Scotia (CORD) (71) developed a simple underwater weighing chair (Figure 13) connected to an electronic scale and load cell. This was found to give reliable repeatable measurements of the additional buoyancy of a suit system when worn by a human. Morepver, because it completely immersed the subject in the simulated crash position, it represents a condition close to that which would be experienced by a survivor in a true water ditching situation.

An observation of particular interest, which had not been previously noted, was that trapped air in all commercially-available suits, liners, and underclothing which potentially could vent off would do so in less than 10 seconds after total immersion. This is a benefit because it is a factor in reducing the inherent buoyancy of the suit system just prior to escape. Thus, an upright or vertical 15-second dunked buoyancy reading was considered to be a good measurement of the suit system buoyancy. These readings were later validated when the seat was transferred to the inside of the Helicopter Underwater Escape Trainer (HUET). Subjects were weighed underwater, upside down, 15 seconds after immersion in a standard helicopter ditching procedure. The suits recorded, by and large, the same buoyancies in the inverted dynamic conditions of the HUET as in the upright or vertical chair condition . The only discrepancies were data for those suits which were poorly fitted and/or poorly designed. These suit systems leaked badly under both conditions, but worse in the HUET because it is a much more aggressive test and can break watertightness of zips and neck and wrist seals. Hence, in the HUET, these suits became relatively heavy. The air in the lining was displaced with water and therefore buoyancy was less than under similar circumstances in the vertical dunked buoyancy measurement. Normally, in the process of commercial acceptance tests on such suits, the suits would have failed because they would not pass the thermal test due to the gross leakage, so these discrepancies were not significant.

Once a simple method of measuring a suit system buoyancy had been established, it was possible to measure the buoyancy of the then current commercially-available suit systems being used by the crews and passengers of helicopters flying off the Eastern seaboard of Canada, and used in survival training in the HUET by Survival Systems Limited of Dartmouth, Nova Scotia.

Purely by coincidence, Bohemier et al (14) at Survival Systems Limited, Nova Scotia had noted that students using two types of these suits in the HUET occasionally got into trouble while making escapes. They were observed to be just too buoyant and the subjects had to be assisted out by one of the safety divers. With the new technique for buoyancy measurement, these suit systems measured 155N (37 lb) and 169N (38 lb).

Brooks et al (16) reported a preliminary study with four test subjects (three male, one female) to assess their escape capability using these two suits. The conclusion was that the suit system buoyancy must be less than 155N (37 lb). For the suits to meet the thermal requirement, it was considered that the suit system could not be constructed with less than about 146N (35 lb), particularly for the large sizes. A further group of subjects (six males, four females) were evaluated during a relatively complex underwater escape wearing exactly 146N (35lb) off added buoyancy. All escaped successfully, and the CGSB were advised that this should be the maximum allowable inherent buoyancy for the Canadian-approved passenger helicopter immersion suits (71). This value now has been incorporated into the CGSB Helicopter Passenger Transportation Suit System Standard (21), and the technique for measuring the buoyancy of a suit system has been made an Air Standardization Coordination Committee Air Standard (2).

It is therefore important to ensure that the buoyancy is kept to the minimum. Passengers must know not to inflate their life preservers before making their escape, another reason for a good preflight briefing. Practical underwater escape training should demonstrate the profound effect of being pinned to the inverted floor of the submerged helicopter.

2.5.11 Harness Release

While undoing the buckle of the lap strap in air is a simple task strapped in an aircraft seat sitting normally uprighted, it can be extremely difficult to do upside down when completely submerged in water. Rice et al had recommended water-actuated time-controlled release of lap belts in 1973 (60), yet no such device is fitted to any helicopter fifteen years later. The U.S. Navy Safety Center reported 14 cases of difficulty releasing the restraint system in the three years 1983-1985. Moreover, if the general anatomical structure of the seat and surroundings has been disarranged by the accident, the problem is compounded by sharp edges which can cause serious entanglement. For the same period, the U.S. Navy reported 31 cases in which the crew were hampered by equipment. Preliminary results for 1987 compiled by Thornton (19), indicated a further three cases, in H-46 Sea Knight accidents. The problem of harness release is very well demonstrated in the following narrative to an accident in which one passenger was lost at sea and one suffered hand injuries.

> Engine malfunction in a USN H-46 Sea Knight helicopter in flight led to an unsuccessful attempt at a single engine landing aboard the flight deck of a ship. Ditching was elected when it appeared that a successful landing could not be accomplished. Seven passengers egressed underwater through openings created where the aft section broke just aft of the stubwings. Four of seven passengers had difficulty releasing their seat belts. Two passengers had to add more air to their life preservers, one passenger's foot got caught in the seat during egress, and one passenger's web seat collapsed on impact with water due to the locking rod under him not being secure. The co-pilot egressed underwater through the right escape hatch.

He had forgotten to disconnect his communication cord. The lobe of the pilot's life vest caught during his egress from left escape hatch. The two crewmen egressed underwater through upper hatches of the passenger doors. Hatches slid shut on both of them. The first crewman pulled the hatch back and tried to egress again. The rotor blade bent down pinning his head against the fuselage as the helicopter continued to roll. He got free and proceeded hand-over-hand to pop out of a hatch on the port side. He surfaced, inflated his life preserver, and turned on his radio. The helicopter rolled over seconds after he egressed. The pilot had climbed on to the fuselage upon egress. As the helicopter continued to roll, he fell backward into water. He swam a few feet away and inflated his life preserver, put his radio on emergency beacon and strobe light on his helmet. Rescue was completed within 25 minutes. The co-pilot had difficulty climbing the cargo net when boarding ship.

In the pre-flight briefing and particularly in the Helicopter Underwater Training Course, it is essential to stress the importance of remaining in the seat until all motion has stopped, and only then releasing the harness; otherwise the only physical reference that the survivor had is lost. It is also important to emphasize the necessity to tuck the "tail" of the lap strap inside the tightened lap belt. This prevents the flap from interfering with efforts to locate the buckle. Although, by and large, the pilot and co-pilot will tend not to have too much difficulty in escaping, providing they are not injured, passengers with as little as four metres (approximately 12 feet) of distance to the nearest exit may indeed perish, particularly if their escape route is blocked by a panicking survivor, debris from the wreckage or personal equipment. Escape routes must be well lit. Manufacturers should be encouraged to design escape routes that are minimal in distance and that can be followed with eyes closed. Ideally there should be a push-out window adjacent to every seat or row of seats.

2.5.12 Escape Hatches

It is essential that an escape aperture is adequate for the survivor to be able to squeeze through it. The single and multi-seat liferafts must also fit through exits and hatches. Chapter G4-3 of the British Civil Airworthiness Requirements describes the four types of passenger emergency exits (I-IV), the smallest type IV dimensions being 483 mm (19 inches) wide by 660 mm (26 inches) high. The number of each type of exit is laid down in relation to passenger seating capacity. In addition to the standard requirements, the Super Puma helicopter has fitted also secondary escape hatches 432 mm (17 inches) wide by 483 mm (19 inches) high to enhance escape from a submerged cabin. A recent study was conducted by Allen and Ward at RAFIAM to investigate whether this smaller aperture is large enough to pass through while wearing a commercially-available life preserver and immersion suit (6). It was concluded that underwater escape for subjects up to the 95th percentile bi-deltoid breadth would have no problem escaping underwater from such a window aperture. Exits down to the size of 432 mm (17 inches) by 356 mm (14 inches) were also compatible with escape for all but the exceptionally large persons. A second important observation from their experiment for consideration by the designers of safety equipment was that protrusions or snags over the back of the passenger pose a greater risk to escape than those over the abdomen.

As has already been clearly demonstrated, helicopters ditching in water commonly invert and sink; it is surprising, therefore, that no helicopter designer has considered the idea of extending the windows designated for escape right down to the floor of the helicopter in order to reduce the problem of overcoming inherent buoyancy when inverted. As early as 1973, Rice and Greear (60) recommended that more hatches be provided both overhead and in the deck, and that water pressure activated charges be fitted to remove the hatches automatically in the event that the crew could not release them normally. The U.S. Navy, in the three year period 1983-1985, reported 33 cases in which personnel had difficulty or found it impossible to open the escape hatch. Little progress appears to have taken place since Rice and Greear's recommendations.

The design of escape hatch emergency jettison levers is simply abysmal. This was apparent in a recent midwinter flight from Tuktoyuktuk in Northern Canada offshore to a rig in the Beaufort Sea. It was observed that,to release the passenger door/window of the Bell 214 helicopter in an emergency, it is first necessary to remove a small blanking plate which covers the handle. This can not be done with a gloved hand because it requires a small diametered finger to be inserted through a hole in the cap. Then, gripping with the finger and thumb, it is supposed to be pulled off to access the release handle. But the mechanism underneath was impossible to identify and the technique, force and direction to initiate door/window jettison was also not indicated or obvious! Lastly, with four large adults sitting line abreast on the bench seat in the helicopter, it would have been quite impossible to get one's elbow and arm anywhere near the release mechanism!

2.5.13 Underwater Breathing Apparatus

Once the potential survivor, in darkness, upside down and completely submerged in freezing water, has released the restraint harness, become untangled from the head set, analysed which escape path to take, and struggled across debris, broken seats, brief cases and disoriented passengers, he/she likely has run out of air and is panicking. This may have been a factor in the death of one member of a USN H-3 Sea King crew in the accident described below.

While in a night ASW sonar hover, the pilot of a Sea King experienced total gyro failure. The crew conducted an emergency freestream with the helicopter impacting water after sonar recovery. It impacted the water under forward speed in a nose high, left yaw attitude with water immediately entering from the right side and the aircraft rolling right to the inverted position. One crewmember was lost at sea. All rescued crewmembers exited the aircraft underwater as it was flooded and became inverted. The pilot egressed through left window, co-pilot through right window, and third crewman through port window across from the left sonarseat. The second crewman braced himself with his arms at impact to avoid injury. He punched out his window immediately. He attempted to exit via the window, but became stuck half way out. Needing air badly he inflated his vest which pulled him out of the window and to the surface.

In order to make a successful underwater escape, it is essential that the survivor be able to hold his/her breath for a period of time. Tansey, in his review (70) of Medical Aspects of Cold Water Immersion, concluded that a subject immersed in cold water at the end of an expiratory phase of breathing risks the likelihood of uncontrolled aspiration of a large volume of water. Moreover, current research indicates that there is a direct correlation between immersion in decreasing water temperature (TW) and duration of breath-holding ability (BHD) (24).

This first became apparent between 1977 and 1979 when the US Coast Guard (USCG) lost a utility boat and two helicopters in cold water. In the first incident, eight crewmen were trapped in a large air pocket in the capsized utility boat. Only a relatively short swim was required; yet the survivors found it difficult to hold their breath in the 7°C water and most survivors had to make repeated attempts before they succeeded. Two of the crewmen perished because they couldn't hold their breath long enough.

Of the two helicopter ditchings, only three of the nine crewmen escaped from the inverted flooded cabins. In water temperatures of 13°C and 14°C, effects on breath holding ability were implicated as one of the possibilities for the drowning. Sterba and Lundgren (69) studied breath-holding duration (BHD) in subjects immersed in 15-35°C water. They found that at 15°C, the BHD was 30% of non-immersed values. Hayward (32,58) showed a 25-50% reduction in adult breath-holding ability in 0-15°C water compared to relatively warm water, and he suggested a dependence (TW) according to the equation BHD = 15.01 + 0.92 TW. For adults in a group of 87 subjects aged from 4-13 years. This problem of a reduced breath-holding ability is exaggerated by the increase in respiratory drive, or 'gasp reflex' as it has become known. Keatinge and McCance (38) observed that cold water immersion caused stimulation of cutaneous cord receptors in humans, producing sudden deep inspiration. Both Martin and Cooper (45) and Hayward and Eckerson (33) noted a four-fold increase in ventilation during head-out immersions; the latter also noted a doubling of frequency and a tripling of tidal volume. This was reconfirmed by Mekjavic et al (46) during recent tests of immersion suits. Expressed in a more practical way, this means that helicopter crews would only have between 12 and 17 seconds at 0°C to hold their breath, hardly long enough to make a simple escape, never mind a complex one!

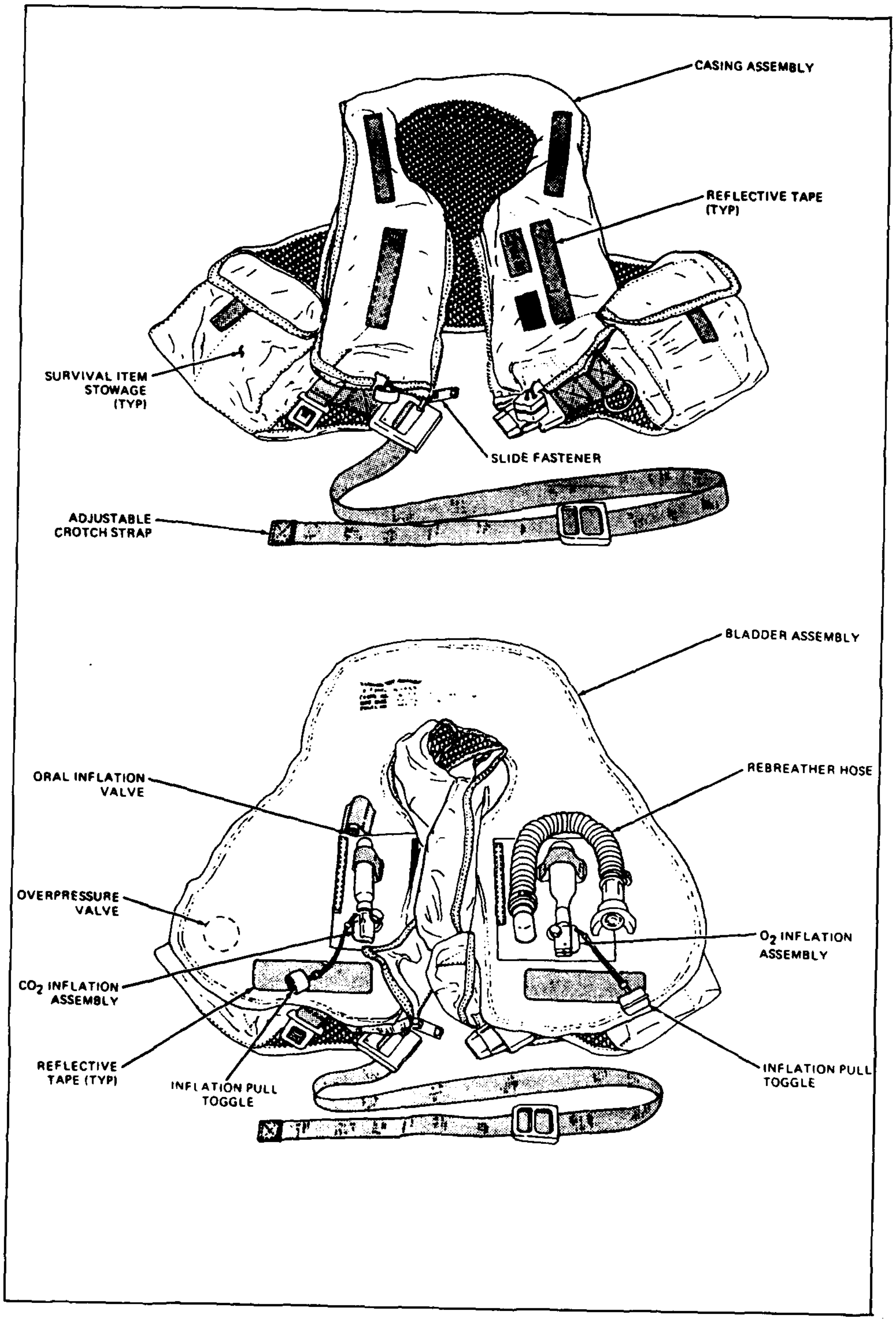
The first work on underwater breathing systems for helicopters was done by the Royal Navy. In September 1974 (72) the Flag Officer Naval Air Command stated it was desirable that underwater emergency breathing equipment be developed to assist troops/passengers to escape from sunken helicopters. From original ideas from Prince, Miners and Bartholomew, a helicopter emergency breathing equipment (HEBE) device was constructed and tested in June 1975 by the Royal Naval Survival Equipment School (61). They recommended that HEBE be introduced into service. To date the Royal Naval Air Command had not implemented the recommendation.

In 1977, Ryack et al (64) tested a prototype SCUBA apparatus manufactured by Robertshaw Controls of Anaheim, California. The investigators were testing the effectiveness of escape hatch illumination and had issued each subject with the breathing device to assist in escape if they became disoriented. The short report described how six subjects became disoriented and/or entangled within the helicopter. In four cases, the subjects used the breathing device to assist them out of difficulty, with good results. The availability of a breathing device was strongly recommended by the subjects and the investigators.

As a result of a 1979 H-3 U.S. Coastguard Sea King helicopter accident off Cape Cod, in which four of the five aircrew drowned while attempting underwater escape, the USCG decided to develop their own underwater escape breathing system. The prototype system consisted of a modified dual-cell life preserver. One cell of the preserver contained an oral inflation tube and 28 gram CO_2 cartridge; the other cell, had a mouthpiece with breathing tube and a 12-litre compressed oxygen cartridge (Figure 14). Upon immersion, the oxygen cartridge was manually activated by a pull toggle and inflated the left cell of the preserver with 100% oxygen. The system was combined into a prototype life preserver/survival vest combination in 1981.

The re-breather system was physiologically evaluated by the USN Experimental Diving Unit early in 1981 (31). The primary criticism of the system was the significant suppression of the hypoxic drive and a tendency toward the development of hypercapnia and loss of consciousness while breathing 100% oxygen underwater. "Removing the hypoxic drive caused the subjects to continue re-breathing well beyond the point where their mental state would be adequate for helicopter egress". It was therefore recommended that the 100% oxygen be replaced with a 60:40 nitrogen/oxygen mixture to create sufficient

Figure 14. The U.S. Coastguard LPU-25/P Survival Vest Assembly/Underwater Escape Rebreather.



dyspnea to warn of impending CO2 intoxication and blackout. However, in retrospect, it does appear that the USN misunderstood that this was designed specifically as a shallow water escape device that would commonly be used for 30 seconds and never for more than two minutes. Therefore, despite their recommendation, the USCG proceeded with re-breather development using 100% oxygen, rather than with either air or 40% oxygen, because of the significantly longer breathing times. The product, Model No. 81340/81 UER 108-1 , is now in service. It is made by Soniform Incorporated, El Cajon, California. To date, there has not been an accident in which a USCG pilot or crew member has needed the apparatus.

In 1979, the Defence & Civil Institute of Environmental Medicine (DCIEM) in Toronto decided to proceed with the investigation of alternate compressed gas systems too. The system originally developed and tested in prototype form by Ryack et al (67) was now commercially available from Robertshaw and was acquired for DCIEM evaluation (Figure 15A). It consisted of a coiled stainless steel tube reservoir containing 130 litres of air compressed to 5000 psi. From the reservoir, a 22-inch hose with in-line quick-disconnect fitting connected to a miniature demand regulator mouthpiece. The air supply was initiated by a pull-to-start ring at the base of the unit. Underwater evaluations by the Diving Division at DCIEM during 1981 revealed that during a moderate workload of 75 watts at 10 and 30 fsw, the average breathing times were 3 and 2.5 minutes, respectively. In addition, it was found that the regulator mouthpiece occasionally filled with water, requiring excessive purging to clear, thus depleting the air supply quickly. The leakage was thought to arise from inadequately designed flapper valves on the regulator mouthpiece exhaust port, or from some design deficiency in the regulator itself. Consultation with the manufacturer revealed that re-design would result in the price per unit becoming prohibitive. As a result, this design was abandoned.

In the latter half of 1982, another commercially available emergency breathing system (EBS) was identified (Figure 15B). This was designed specifically as an emergency supply for divers. It was thought that it could have potential as an underwater escape system for aviators. Manufactured by Submersible Systems Incorporated (SSI), Huntington Beach, California, it consists of a 15-inch long, 2-inch diameter "monoblock" aluminum cylinder containing 56 litres (2 cu. ft.) of air pressurized to 1800 psi. A single-stage demand regulator incorporating a twist-turn on/off knob, rubber mouthpiece, purge button, pin-type pressure gauge, and refuel port was attached directly to the cylinder head. The cylinder itself had been approved by the Canadian Ministry of Transport and could be repeatedly re-filled without inspection. Overpressurization during refill was prevented by the incorporation of a frangible brass disc designed to burst at 2700 psi. The cylinder itself is designed with a minimum burst pressure of 6000 psi. The EBS is available in single or dual cylinder configurations (Figure 15C).

Operation of this system is simple. The rubber mouthpiece is placed in the mouth either before or after the knob is rotated counterclockwise to open the bottle, and the user either exhales or depresses the PURGE button momentarily to clear the regulator of water, and then breathes normally through the demand regulator.

In 1983, 16 test dives at 10 and 30 fsw were carried out with these units. Respective breathing duration times averaged 96 seconds and 78 seconds for a single cylinder. It was recommended that a number of these units be procured for user trials and flight evaluations (36).

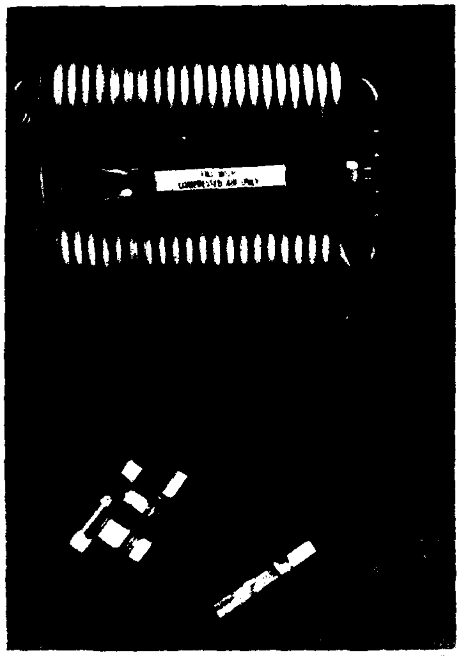
A user trial was undertaken by the Sea King pilots at CFB Shearwater, Nova Scotia. They were satisfied with the apparatus, in principle, provided consideration was given to placing the unit in the survival backpack. Thus, the manufacturer was requested to modify several EBS units to a Mark II design by inserting a 24-inch high-pressure hose between the bottle head and the mouthpiece regulator (Figure 15D). This modification is now complete and has been tested. The first two EBS training courses were completed in August 1988 and it will go into service shortly.

At the same time that the Canadian Forces were evaluating the latter SSI/EBS system, the USN was conducting an evaluation of both systems the USCG and SSI/EBS systems, designated by them as Helicopter Emergency Egress Devices (HEEDS) 1 and 2, respectively. Formal operational evaluations commenced in March 1985. Although the USCG system (HEEDS 1) was able to provide a required two-minute breathing supply at 20 fsw and 55°F, the buoyancy of the inflated oxygen cell was found to interfere with a test subject's ability to locate and manoeuvre out of emergency escape hatches. As a result, Naval Air Systems Command terminated testing of the system. The SSI/EBS (HEEDS 2) was successfully tested and approved for production. Hardware deliveries to the US Fleet began in September 1986.

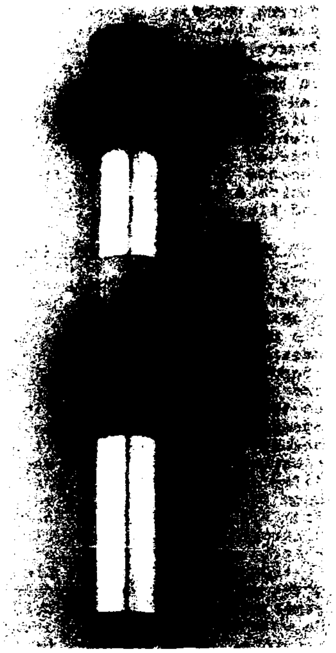
The HEEDS 2, also designated the SRU-36P, is now in service with the USN and, as recently as August 1987, the first units proved their worth. The extensive narrative below illustrates the role of the HEEDS and egress training played following the crash of an H-46 helicopter at sea on 27 August 1987.

> This was the first reported accident in which an aircrew used HEEDS to escape from a sinking aircraft; two aircrewmen's lives were saved. Prior to deployment, all aircrew on the detachment received HEEDS training through an accelerated training program provided by the NAS Miramar Aviation Water Survival Program (NAWSTP). Also, all four crewmember's escape was directly attributed to the underwater egress training in the helicopter underwater escape trainers at/or NAS Miramar and NAS

Figure 15. Different compressed air types of helicopter underwater escape breathing apparatus.



A. The original Robertshaw Control model.



B. The first single cylinder model from Submersible Systems Inc.

C. The first dual cylinder model from Submersible Systems Inc.

D. The DCIEM modification with flexible hose and method for stowing in backpack.

Pensacola (9D5).
The helicopter crash occurred in the western Pacific during daylight hours in moderate seas. The helicopter experienced a material failure in the transmission during recovery at the bottom of a maintenance autorotation that resulted in a full power loss. The pilots continued the autorotation and impacted the water in a 10-15 degree nose up, wings level attitude. The helicopter sank immediately, and all four crewmembers escaped; the pilot and crew chief exited the aircraft underwater and swam to the surface. They did not use HEEDS, but did employ underwater egress techniques and training procedures learned at NAWSTP which enabled them to exit the aircraft safely. The crew chief also exited and swam to the surface immediately with no problem. The pilot was stunned and disoriented after exiting. He immediately reached for his HEEDS bottle and attempted to use it but couldn't open his mouth because of intense pain from a broken jaw. He used a blast of air from it to indicate the direction to the surface. Once oriented, he inflated his life preserver and floated to the surface.

The co-pilot and second crewman both used HEEDS to escape. Following impact, the co-pilot was pinned in his seat by debris from a collapsed instrument panel. His body position was approximately horizontal and his face was turned down and underwater. He was stunned and disoriented, but used the HEEDS bottle. He had no problem pulling the bottle from the zippered vest and placed the bottle parallel to his body and began to breath. He did not clear the regulator before taking the first breath of air, but it had no apparent effect, other than a small amount of water trapped in the mouthpiece. Even after impact, the regulator worked satisfactorily and he was able to breath normally. The HEEDS bottle had an immediate calming effect on the co-pilot. The bottle allowed him time to become oriented and concentrate on egress procedures. He removed the instrument panel from his legs, released his harness,exited the aircraft and swam approximately 15 feet to the surface and breathed regularly while ascending. Once on the surface, he inflated his lifepreserver. He sustained a minor cut under his chin which is assumed to have been caused by the HEEDS bottle. The second crewman in the cabin section was thrown from his seat to the cabin floor. He was on his knees in chest deep water as the aircraft sank. As the water rushed in, he recalls being dazed and disoriented, but alert. He took a breath of air and reached for his HEEDS bottle. He easily removed it from the vest pouch. Like the co-pilot, he did not clear the regulator and was going underwater as he took his initial breath of air. Just as the co-pilot had experienced, the HEEDS bottle had an instant calming effect on the second crewman. He oriented himself in the aircraft, disconnected his gunners belt, exited the aircraft, inflated his life preserver and floated approximately ten feet to the surface. He breathed normally while ascending. Like the co-pilot, the crewman also sustained a minor cut under his chin which is assumed to have been caused by the HEEDS bottle, but the crewman cannot say for sure.
An important fact to be considered concerning this accident is that the HEEDS bottle was credited with saving two lives. The most important lesson learned from this accident is that HEEDS appears to have a calming effect as well as providing additional time for the necessary escape actions. In this case the co-pilot had to remove debris from his legs. Although disoriented, HEEDS restored confidence and allowed sufficient time to regain composure, execute egress procedures in a rational manner and safely exit the helicopter and swim to the surface. The underwater egress training at NAS Mirmar and Pensacola were particularly valuable in this accident since the aircraft hit hard. Consequently several crew had compression fractures of the spine, and the aircraft sank immediately. There were only 5-8 seconds from the initial failure to impact. All crewmembers report that they were stunned and disoriented, but remembered their egress procedures. Even though the actual experience was much more intense and spontaneous than the underwater escape simulator, the training provided by NAWSTP incorporated the necessary skills for proper use of equipment and for a safe egress. Pool, underwater escape, and HEEDS training all proved invaluable in this crash situation; they are considered realistic and essential to crew survival during an actual emergency.

Throughout the USN and the Canadian Forces programs, there have been concerns expressed that a trainee may suffer from an air embolism or burst lung during the training procedure. Three simple steps have been taken to prevent these events occuring either in training or in an accident. First, each trainee must recieve a simple physiological explanation on the hazards of breathing compressed air, with special emphasis on the requirement to exhale on ascent and at no time to breath-hold. Secondly, the Shallow Water Escape Trainer (which will be discussed in Chapter 3.6.2.) is so designed that the trainee's head to mid-thorax level is never more than 105 cm (3 1/2 ft) underwater and lastly, training is limited to a pool depth of 1.5 metres (5 ft).

At the time of going to press, it was discovered that the Italian Navy also uses an underwater escape breathing apparatus. For completeness a brief description has been appended at Annex A.

2.5.14. Immersion Suits

Immersion suits have been used since World War II in order to ameliorate the process of hypothermia when the survivor is immersed in cold water. Applied to the helicopter crew scenario of flying over water, they also reduce cold shock and the gasp reflex, and they enhance underwater breath-hold ability. Equally important, and what some agencies don't realize, is that they also protect the survivor from hypothermia while awaiting rescue in their life rafts.

In order for the immersion suit to be universally acceptable, it must be comfortable under a wide range of ambient temperatures, easy to don and doff, durable, simple to operate, and cheap and easy to maintain. It is, of course, only for the rare occasion in the immersion survival situation rather than in the thousands of hours that it may be worn. During an immersion and until subsequent rescue, it must effectively slow down the hypothermic process. This is a very tall order to expect from a garment; in fact, there is no suit on the market that meets all of these criteria.

In 1986, Brooks (13) reported various problems of immersion suits; the principal difficulties are reviewed below. The market is small, so manufacturers are loathe to make a large range of sizes; and hence, many suits don't fit correctly. On one extreme they are too tight and therefore uncomfortable; on the other, they are too loose and bulky and the wearer has to contend with folds of excess material. In either case, the wearer psychologically feels and physically looks awful in the suit.

Allan (7) in 1983 established very good guidelines for policy makers on how much insulation is required in an immersion suit at different water temperatures. Because water conducts heat 27 times more rapidly than air and the sea water temperature in areas where NATO operates barely reaches the upper teens Centrigrade even in summer, a dry suit must be worn (Figure 16).

A dry suit inherently has a number of problems. It is very difficult to make even a brand-new suit watertight unless it is personally tailored. It is even more difficult to maintain watertightness during its operating life. Continuous rubber seals are required at the neck and wrists to maintain watertight integrity, yet manufacturers often incorporate a neck seal, which invariably leaks. Paradoxically, regardless of type, the seal is somewhat uncomfortable, due to sensitivity of the neck, and difficult to maintain.

To close the apertures of the suit requires a water proof zip, which is not only expensive to make, but expensive to maintain. This compounds the problem of keeping the suit watertight. Neoprene nylon fabrics are durable, but extremely hot to wear. Ventile fabrics are vapour permeable, but only waterproof when new; moreover the fabric is difficult to weave, make up into suits, and consequently is expensive. Finally, Gortex-laminated fabrics are very expensive and not as vapour permeable as would be of practical benefit. Only the latter can be bonded with Nomex or a similar fire retardent material. The ideal fabric would be durable, fire retardent, vapour permeable yet waterproof, comfortable to wear and inexpensive; but no such fabric exists. Unfortunately too, the newer insulation liners made from blown polyester microfibres marketed under such trade names as "Thinsulate", lose their insulation when soaked, just like all others and offer little advantage over previous lining materials.

Besides the problem of maintaining the water integrity, there are other problems. Because of the need for trapped air inside the outer shell of the suit to provide insulation, flotation angle of the survivor is affected by the immersion suit. Thus, it is impossible to achieve the "ideal" position of lying 45° in the water facing the oncoming waves. All suits,without exception, force the survivor to lay horizontal in the water. Buoyancy from the air trapped in the suit may also aggravate disorientation and hinder or even prevent escape from a ditched inverted helicopter, if the buoyancy is so great that a survivor cannot swim down to an escape hatch or window. Various valves have been developed to let out excess air, but to date, the valves either leak badly or don't work at all. There is a new type of valve that shows promise, but it is still not in service with any manufacturer; it is undergoing testing at the Robert Gordon's Institute of Technology, Aberdeen.

In summary, the principle of immersion suits has not changed in the last fifty years. They are expensive, uncomfortable and unpopular with wearers and operators and, in their current design, are difficult to maintain and commonly leak. The time has come for new ideas in design.

2.5.15 Equipment Design Improvement

This chapter so far has discussed direct survival factors on the human when confronted with sudden immersion and possible inversion in cold water. There are however a number of indirect factors related to the overall general design of helicopters which effect survival and there is room for improvement.

(i) Helicopter Flotation

As previously observed in Chapter . helicopters are inherently unstable in the sea. The work horse of the USN, the H-3 o. Sea King is designed to stay afloat in a sea state 3 (with wave height 0.5 - 1.25 metres) with bouyancy bags deployed (76). The U.K. Marine Information/Advisory Service confirm that the wave heights for instance in the Northern North Sea at the Stevenson Station (61° 20'N 0 E) are as follows:

DEC - FEB	3 metres	exceeded	65%	of time
	5 metres	exceeded	20%	of time
MAR - MAY	3 metres	exceeded	25%	of time
	5 metres	exceeded	8%	of time
JUNE - AUG	3 metres	exceeded	28%	of time
	5 metres	exceeded	1%	of time
SEP NOV	3 metres	exceeded	28%	of time
	5 metres	exceeded	5%	of time

It would therefore appear that even the Sea King helicopter, which is relatively well configured for flotation, has a high chance of capsizing under such conditions. What can be done about this problem? Is it possible to increase the flotation characteristics of the helicopter?

The French Navy have fitted special flotation bags to their Alouette II and Alouette III helicopters which appear to work well; the underside of their large troop carrying Super Frelon is also deliberately boat shaped to assist in flotation.

More recently the Saudi Arabian Armed Forces Medical Services have purchased two emergency flotation kits for their Bell 212's. It was developed by Westland Aerospace and Bristow Helicopters and is adaptable to the Bell 205 and 412. There are twelve currently of these kits in service world-wide.

King (40) also studied the possibility of increasing the stability of the H-46 Sea Knight helicopter by the addition of four externally encapsulated spherical flotation bags in two nose-cone and two stub-wing pods. The system could be inflated automatically or by the pilot in under ten seconds. The penalty was that the whole system weighed 220 lbs. The U.S. Navy has recently approved the H-46 Helicopter Emergency Flotation System for full production in 1989 (73).

The CAA as previously mentioned consider that it may be more practical to accept that it is impossible to keep the helicopter afloat, but design into new helicopters the ability to remain on the surface for ten minutes to allow everyone to egress into the liferafts before sinking.

The USCG have recently accepted into the service the Aerospatiale Dauphin II which, theoretically, should float tail up and maintain water integrity in the cabin and passenger compartments. Schreiner Airways had a recent accident (19/4/88) approximately 45 miles of the Dutch Coast in a Dauphin 365-C3 as follows:

> The pilot decided, on an overshoot from the ship due to disorientation caused by floodlights on the bridge, to make a right hand circle for landing. During final, the helicopter hit the water in a slight nose down, left sideways motion with about 15 kts forward and 8 kts sideways speed. The two pilots and three passengers had no warning. The helicopter turned inverted, floating bottom-up on the bouyancy tanks and tail section. Everyone escaped from underwater successfully.

The helicopter acquitted itself very well. Even though it inverted, at least after a severe impact, it remained afloat allowing the crew and passengers to escape. It would therefore now appear to be technically possible to manufacture a helicopter fuselage that will withstand relatively high impact forces and stay afloat even if it is inverted. The next step should be to develop escape hatches in the floor or at least extend the push out windows to floor level. This would make ease of escape in the inverted position much simpler.

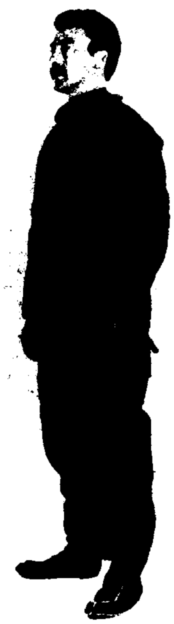
(ii) Liferaft Deployment

A fundamental flaw in the concept of escape survival is that all multi-seat liferafts are stowed internally within the cabin of the military helicopter. Anyone who has attempted to escape from an inverted rapidly-sinking helicopter or from an escape trainer would understand that while completely submerged and holding one's breath in darkness, it is against all sense of survival and reason to go in a direction opposite to that of the escape route to attempt to release and deploy a liferaft. It is a simple fact that deployment of an internally-carried liferaft from an inverted submerged helicopter is virtually impossible. Yet helicopter companies show little interest in vacuum packing liferafts and mounting them so that they can be externally jettisoned and illuminated on inflation. King (40) conducted a study in 1976 for Boeing Vertol and confirmed that it was possible to mount two fifteen-man liferafts externally on the USN H-46 Sea Knight helicopter, but little progress appears to have been made since then. Only recently, the RAF have developed a system for mounting them on to the Sea King helicopter; it is very close to production standards, but lack of funding has caused the project to be put on hold.

Figure 16. Principle types of helicopter survival suits used in military and civilian operations.

A. CF double layered cotton ventile suit,
- Horseshoe zip.
(Courtesy Mustang Industries Inc.)

B. CF Quick-don suit, - Semi-vertical zip.



C. RAF upper half single layered cotton ventile suit for NBC conditions.
- Diagonal zip.
(Courtesy Dunlop - Beaufort Ltd.)

D. USN Gortex Nomex suit. - Transverse zip.
(Courtesy N.A.D.C. Warminister. Pa.)

In the North Sea, civilian operation progress has been better; there are now three types of helicopters fitted with externally mounted rafts: the Puma, the Sikorsky S76, and the Bell 214. The following Norwegian accident describes the problem of inability to deploy the life rafts:

> During low level training at 30 feet and 90 knots, a Norwegian military Sea King MK43 hit power lines. Six metres of the tail boom was ripped off and the helicopter, under partial control, crashed into a small lake with a force of approximately 10G. The helicopter rotated to the left and filled with water. The two pilots (the only ones wearing seat belts) evacuated through the forward right window after problems with the emergency exit. The flight engineer evacuated through the emergency exit in the personnel door, the rescue specialist through the emergency exit in the cargo door, the system navigator from a fixed wing squadron, probably through the emergency exit in the personnel door. He was the only one who had not had underwater escape training. The navigator and some of the other crew ingested floating JP-4, were vomiting and had problems seeing. The helicopter sank shortly after everyone had come out. Only the pilots and the navigator had life preservers and no one was wearing immersion suits. No one managed to bring dinghies out. In a water temperature of 1 C, the pilot starting swimming, followed by rescue specialists and the flight engineer reaching the nearest shore about 70 m away in 8-10 minutes.

This is a typical case in which the accident occurs so quickly that the occupants, in immediate danger from drowning, do the most obvious life-saving action, which is to get out of the helicopter and to the surface as quickly as possible.

Elliot (50) observed, in his preliminary review of 12 of the 16 helicopters ditching into the North Sea between 1970 and 1986, that only four helicopters' crew or passengers had managed to deploy the rafts. In one of these cases, the raft would not inflate; in one case, it was punctured, and in one case, it was not used; so, only in one case did the raft actually work as advertised! Another similar example of this was after a Royal Navy Lynx helicopter accident, described below.

> Two airmen jumped into the sea while the pilot held the helicopter in the hover. The pilot then ditched and made a safe exit. The cabin flooded upright for a few seconds, inverted and then sank within two minutes. This happened 42 miles from the parent ship and it was 70 minutes later before the crew were picked up by Gemini. The multi-seat liferaft was lost and the three men took turns in using the two single man dinghies. The sea water temperature was 8.9°C.

Military operators should be aware of the externally mounted liferaft system fitted into the Bell 214 ST described in their training manual as follows:

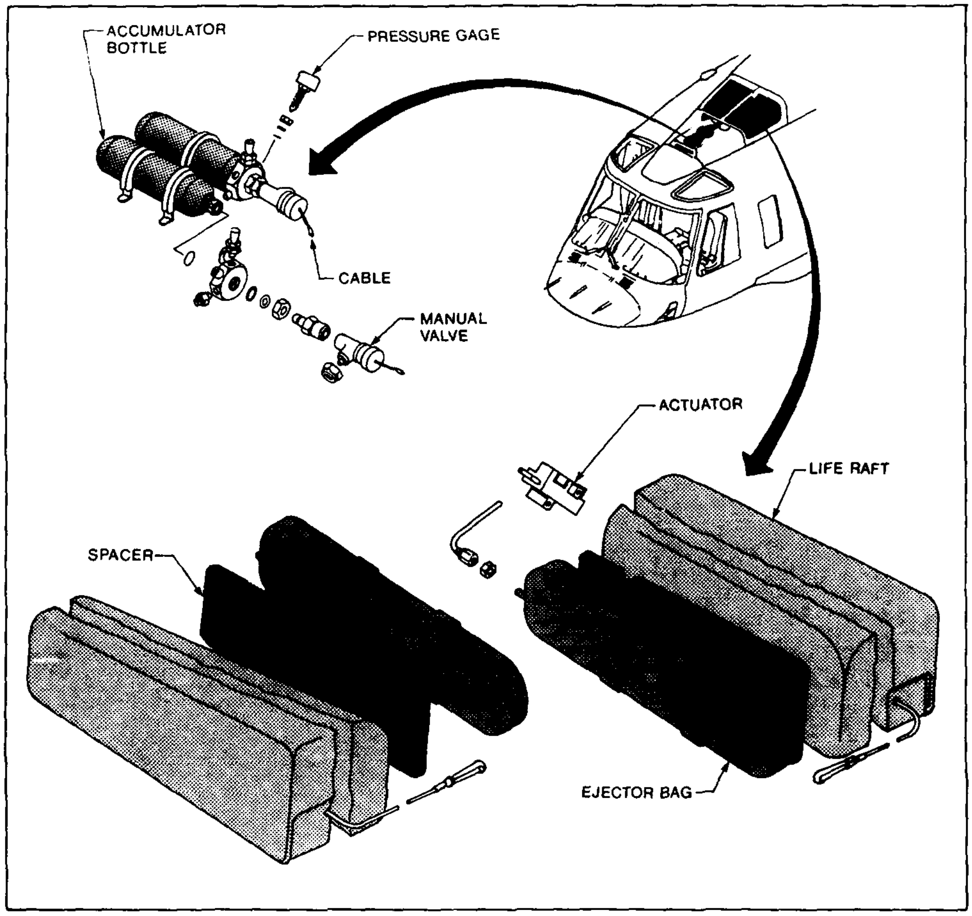
> "The emergency liferafts system consists of two raft assemblies, ejector bags, accumulator bottles, mechanical devices, and connecting hardware. Two rafts assemblies are installed beneath exterior doors, above and aft of the cockpit (Figure 17). The doors are opened automatically when the rafts deploy; also, they can be opened manually with internal handles.
>
> The accumulator bottles are located just forward of the raft assemblies. Each bottle is charged with dry nitrogen to approximately 2,000 psi. The bottle pressure can be verified by reading the attached pressure gauge. Each bottle is fitted with a manual activation valve connected to a single crew actuation ring located on the cockpit overhead.
>
> When the crew actuation ring is pulled, the bottles discharge air into the ejector bags and mechanically release the doors. As the ejector bags inflate, the raft assemblies are deployed. Each raft assembly is attached to the helicopter with a lanyard, and as the raft assemblies fall overboard, they reach the end of the lanyard. This action activates the raft inflation bottle and the rafts inflate.
>
> The rafts are attached to the helicopter with a 5 metre (16 ft) nylon mooring line so that the rafts remain near the helicopter until the occupants board. The mooring line has a break away feature that operates when sufficient pressure is exerted. This prevents loss of the raft if the helicopter sinks."

Another typical example of difficulty with release of the multi-placed life raft occurred to the Schreiner Airways Dauphin helicopter. The pilot became disorientated on approach to the ship, the helicopter hit the sea, capsized and floated inverted. Four of the occupants sat on the exposed inverted bottom of the floating helicopter while it took 30 minutes for the pilots to release the liferaft!

(iii) Personal Equipment Stowage

Little thought has also gone into the stowage of personal equipment like briefcases, hand luggage and headsets in helicopters. There are many examples in which survivors have been "hung up" during their escape because of such items. A typical example of an accident in which this occurred was that of a USN H-3 Sea King helicopter which, while doing a right approach to the ship, suddenly yawed, rolled to the right and impacted the water on its right side:

Figure 17. The system of externally mounted liferafts on the Bell 214 ST helicopter.
(Courtesy Bell Helicopter TEXTRON and Flight Safety International.)



After impact, the third crewman was thrown forward between sonobuoys and bulkhead still attached to his gunner's belt. First he had difficulty releasing the belt, then as he exited through the cabin door, he became tangled in his headset. He swam clear with the aid of the second crewman and inflated his life preserver on the surface.

Many of the passengers are staying overnight in oilrigs, merchant or military vessels and some of course are on crew change. They all are on business and at the very least carry a briefcase and overnight bag. Many people wish to work from their briefcases on longer flights, others carry pocket books, newspapers and additional carry-on warm clothing. More consideration is needed in the design of stowage for this type of equipment.

2.5.16 <u>Post Escape Problems</u>

Once a person has escaped from the helicopter, whether injured or not, there is still the problem of survival in the open water or in a liferaft prior to rescue. Even the hoisting is not without its hazards!

(i) <u>Life Preservers</u>

There have been several reported cases of crew members unable to find and then grasp the toggles to activate their life preservers. This is made worse with slippery gloved hands. Many life preservers are still made with very small toggles on their activation devices. These can easily be confused with buttons and other accoutrements on the front of the survival suits, flying coveralls, and other work dress. In addition, there are still many life preservers available, both in the military and civilian markets, which require two separate activations, often with separate hands, to achieve full buoyancy. In an emergency, this is not acceptable. Brooks (15) reported on four such incidents in his 20 year study of Canadian Forces aircraft accidents. The crews of two helicopters in this series likely perished because of inability to find the activation toggles. Certainly one aircrew of a fixed-wing aircraft that ditched ahead of an aircraft carrier lost a leg in its propeller because he could only activate one side of his life preserver. With only about eight lbs of positive bouyancy in his life preserver, instead of coming straight to the surface, he traversed the complete hull underwater. The other three aircrew also traversed the hull for the same reason but were lucky to survive without loss of limbs. The following is an accident narrative from a narrative from a USN H-3 Sea King Helicopter which hit the sea following a tail rotor failure. Both pilot and co-pilot had trouble activating their life preservers in daylight:

> The pilot was unable to find his life preserver inflation toggles, swam to surface, found the toggles and inflated his life preserver. The co-pilot was pinned to the left side of cockpit by the spin, prior to impact. He unbuckled his seat belt and exited through the open co-pilot window. He was also unable to find the life preserver toggles. He swam to the surface, took off his helmet and used it for flotation. He found the right toggle, inflated right side of his life preserver and put his helmet back on. He then found the left toggle and inflated it. Both crewmen had problems inflating their raft. They had to remove it from its container and unroll it in order to find the inflator pull handle.

The above incident also illustrates the need for a pre-flight briefing to include post-crash survival and a brief description of how to operate life jackets, life rafts and all personal survival equipment. Often with the noise of downwash from the rescue helicopter blades and engine, it is quite impossible to communicate with each other when in the raft or in the water.

(ii) Life Rafts Reliability and Servicing

Even if the multi-seat life raft is successfully deployed in the water, there is no guarantee that it will always stay afloat, or that the required survival equipment will be stowed in it.

> While en route from the offshore oil rig SEDCO off Sable Island to Halifax Airport, the crew of the Canadian-registered S61 helicopter noted that the main transmission oil pressure was decreasing and that the torque indication had dropped to zero. As the oil pressure continued to decrease, the pilot decided to carry out a controlled ditching in the Atlantic Ocean about six miles from land. During the evacuation of the helicopter, the co-pilot boarded 14 passengers into the forward raft in an attempt to get as many of the occupants as possible away from the helicopter, as he feared the aircraft might capsize. After the pilot-in-command had shut down the helicopter engines and stopped the rotor, he moved aft to the passenger cabin. Once he had passed the airframe-mounted Emergency Locator Transmitter to the passengers in the life raft, the raft was pushed away from the helicopter. As the raft moved into the outer limit of the rotor arc, the stationary rotor blades were swinging in the water dangerously close to the raft, and the occupants had difficulty keeping the raft from being struck by the rotor blades.
>
> After launching the Number 1 life raft, the pilot, co-pilot and remaining passenger inflated the Number 2 life raft beside the aircraft and stepped directly into the life raft. The raft was then pushed away from the helicopter, and it drifted under the tail pylon. The three occupants had difficulty keeping the raft clear of the stationary rotor blades as the helicopter was pitching and rolling in the water. Shortly after the Number 1 life raft was launched, the lower buoyancy chamber began to deflate, and water began to enter the interior of the raft through the boarding entrances. When the raft survival equipment containers were opened, the occupants were unable to find a bailing bucket or oars. In an attempt to remove the water from the interior of the raft, some of the occupants used their protective overboots as bailing buckets. By the time the rescue helicopters arrived, the occupants were sitting in about 18 inches of water. Except for the initial difficulty they experienced clearing the helicopter, the occupants of the Number 2 life raft had no problems during the one hour they were awaiting rescue. When the life rafts and their contents were examined, the following observations were made:
>
> a. There was no reflective tape on either life raft;
>
> b. There were no grab lines on the inside of either life raft;
>
> c. The two entrance areas of the life rafts are outlined with lights which are energized by a salt-water activated battery. The batteries in both rafts were time-expired;

d. Both rafts had several large patches on the buoyancy chambers which were not stamped with the date of repair;

e. Eight D cell batteries were found wrapped in a plastic bread bag and taped closed. All the batteries showed signs of corrosion;

f. One flashlight was recovered and was not in operating condition;

g. Two metal signal mirrors were recovered. The surfaces were not highly polished and were not smooth. No safety lines were attached to the mirrors, nor were there instructions or markings for their use;

h. One of the two flares recovered had a loose striker in the cap. The striker could have been lost when the cap was opened for use; and

j. The expiry date on a bottle of analgesic tablets was past dated, and the tablets should have been replaced during the last raft inspection.

These survivors were lucky that the rescue times were short. Although the accident occurred in winter, it was a calm clear relatively warm day and there were several serviceable Search and Rescue helicopters with rotors turning only a few miles away on the morning of the accident. The next two days the weather conditions deteriorated to the extent that it was impossible to fly. Under those circumstances, they may well have perished because of the poor maintenance of their life rafts.

(iii) Personal Survival Equipment

The first problem is that flying gloves when wet become very slippery and virtually useless for gripping anything, particularly inflation toggles on life preservers. Yet it appears that no one has undertaken research to develop a material that would improve the grip of a wet glove. This may be wishful thinking, but must be worth attempting. The second problem is that the survival aids in the life raft and issued as personal equipment with the life preservers just do not always work when needed. A typical example of this happened to the crew of a USN H-3 Sea King helicopter who became disoriented during transit to rescue a man overboard. The helicopter crashed into the sea and had problems not only with the life preserver but also the location aids:

> The pilot, co-pilot and SAR crewman were thrown from the helicopter. The other crewman left the helicopter underwater through a hole in the side; their life preservers inflated normally. However the SAR crewman did not have a life preserver, he had a life vest which did not inflate despite being actuated. The SAR crewman had only his wet suit and a cushion that was floating near him to buoy him up. In order to be seen, he shone his flashlight on his helmet. The pilot used a red flare, but had a problem seating other flares due to broken threads. JP5 in the water discouraged use of other pyrotechnics. The pilot and the crewman used their radios and the crewman used his strobe and flashlight. The co-pilot had trouble with his radio and used the crewman's flashlight. The SAR crewman being a distance from the others was rescued first. A swimmer from the rescue helicopter was put in the water especially for the SAR crewman as the pilot was already being hoisted; however, the co-pilot was attached to him by a shroud line which was tightly snagged around his legs. As the hoist went up the co-pilot reached for his knife, but the line broke. Once in the rescue helicopter, the return to base was uneventful. All crewmen were hypothermic when brought ashore.

This accident clearly demonstrates that the survival equipment such as flares and radios must be made failure-proof and that materials used for life rafts and life preservers abrasion and puncture proof. Furthermore, the crew must be well briefed on how to use the equipment and on how to provide pre-flight briefings to passengers who have never used it.

(iv) Problems with Hoisting

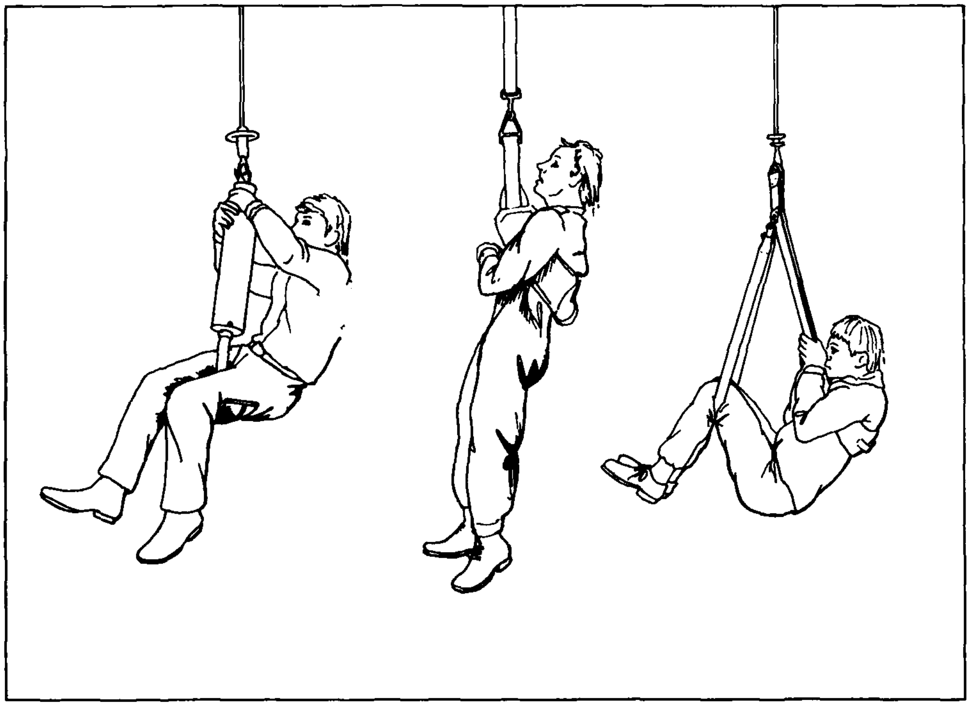
During the 1979 Fastnet race (water temperature 15-16°C), three (20%) of the 15 fatalities among the competitors occurred during the rescue following the storm - one while being rescued by helicopter and two while endeavouring to climb up a scrambling net thrown over the side of a ship.

It would appear that post-rescue collapse and death occurs in about 15-20% of hypothermic victims (29). As Golden pointed out, it may not be a phenomenon entirely limited to exposure in very cold water. The exact mechanism for this has still not been proved; it is unlikely simply "the afterdrop" effect of a "cold bolus" of blood returning to the heart during rewarming (28,30), but more likely to be cardiovascular in origin (29). The current theory is that it is principally due to the sudden withdrawal of the supportive hydrostatic squeeze. Thus, when the body is removed vertically from the water, there is a tendency for the blood to pool in the legs, thus compromising the cardiovascular system. This drop of blood pressure during the hoisting of hypothermic subjects was well demonstrated and reported by Ocker and Koch in 1984 (48).

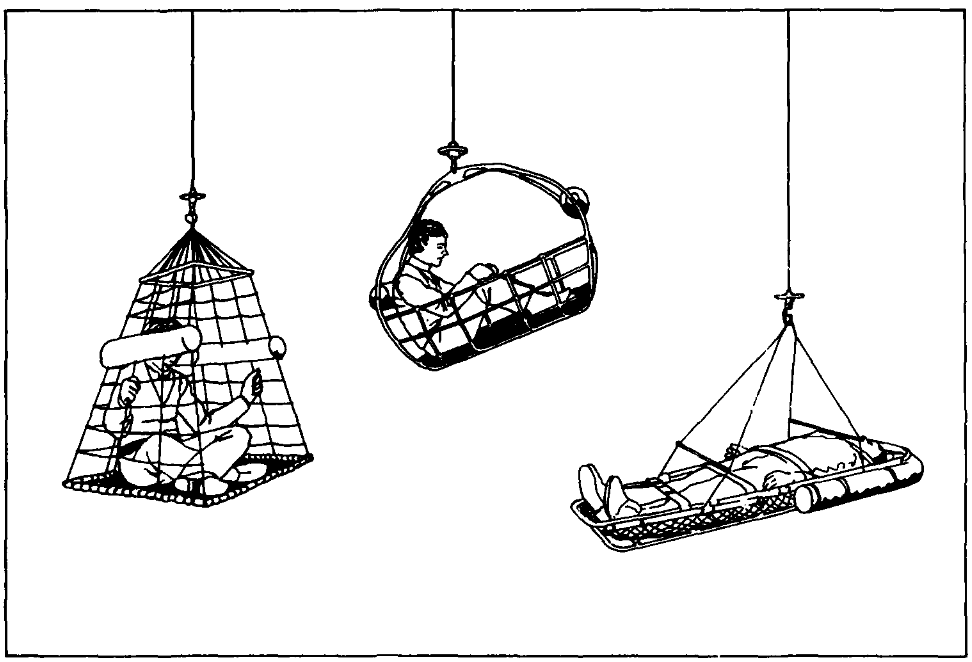
Therefore, for those who are hypothermic, hoisting in a vertical position is not recommended. In spite of this, most rescues are still done using either a horse collar or some form of double-lift harness. Wherever possible, rescuers should be encouraged to use horizontal lifting in devices such as the Billy Pugh nets, U.S. Coastguard style of baskets, or even folding Stokes Litters if there is room for them, particularly if the condition of the survivor is critical (Figure 18).

There are two promising new hoisting ideas, first, the horizontal lift strap, developed and currently undergoing testing by the Royal Navy and, second the concept of picking the complete life raft up by helicopter for multiple casualties. Using their 22-man life raft and a Sikorsky S61 for hoisting, this multiple casualty concept has recently been successfully tested by Viking in Copenhagen with twenty-two 70kg sandbags to represent the survivors. The raft was picked up, flown at 60 knots and landed with no displacement of the sandbags or other problem. This system has the added advantage that the survivors are protected from the wind by the canopy. An early test in Canada, using a large open net called the EMPRA basket that held up to 50 people, was a failure because of the windchill effect on the survivors. If this concept is introduced to prevent overloading it will require a rescue technician to be lowered first of all to control the number of survivors allowed into each raft.

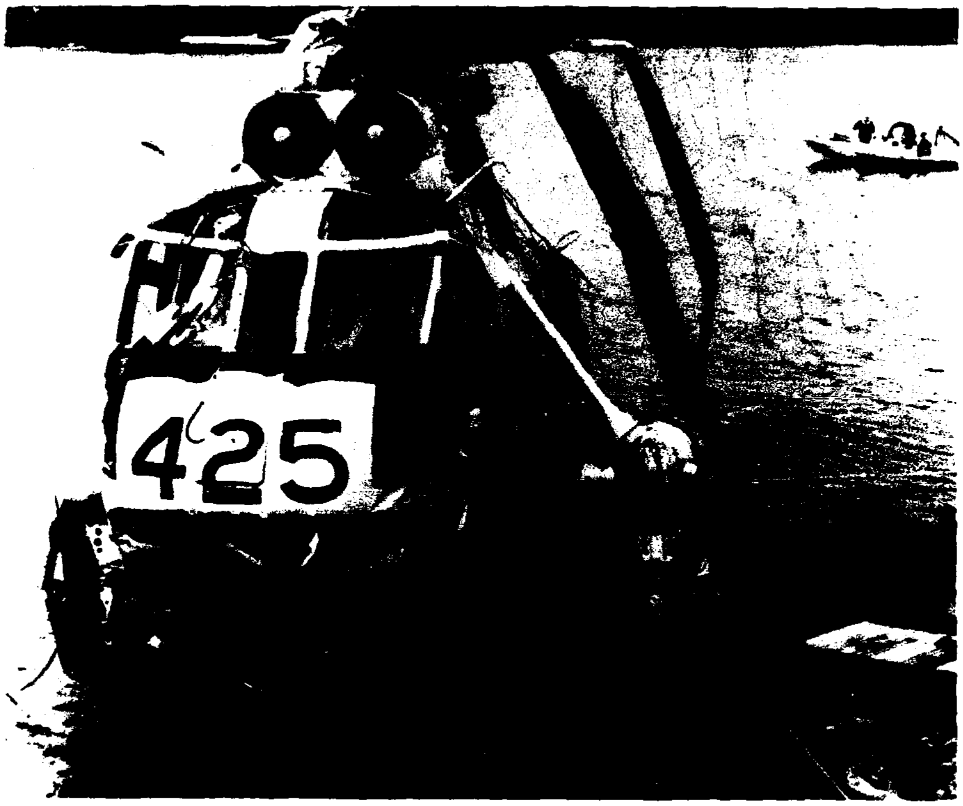
Figure 18. A series of different methods of hoisting survivors from helicopters ditched in water.



USAF Rescue Hoist **Conventional "Horse Collar"** **New Proposed R.N. Sling**



Billy Pugh Net **US Coastguard Basket** **Folding Stokes Litter**



The 4 crew of this Sea King helicopter had less than 15 seconds warning before it hit the water, rapidly inverted and sank. Escape was very difficult and one crewman came close to perishing.

This accident demonstrates the necessity for good underwater escape training.

CHAPTER 3: UNDERWATER ESCAPE TRAINING

3.1 Recommended Course Syllabus

In order to reduce fatalities caused by helicopter accidents in the water, it is essential to have a good practical training program. This short narrative, in conjunction with the previous ones, illustrates the reason why.

> During a night ASW operation, the USN helicopter impacted the water, rolled over and sank. All aircrew egressed the helicopter underwater. The pilot made three unsuccessful attempts to jettison the window. He then opened the sliding window, pulled himself halfway out, inflated his life preserver, cleared the helicopter and floated to the surface. The second crewman's window was pushed in by in-rushing water. He became momentarily disoriented. On first escape attempt, he struck his head. On second attempt, he felt for familiar objects, regained his orientation, and exited through the window. Both the co-pilot and first crewman were able to jettison their windows while still above water. The first crewman had no difficulty during egress, but his lack of underwater escape training could have prevented safe egress, if he had been on the low side of aircraft. The crewmen ended up in two groups on the surface with the helicopter in between them. There was no coordination in the use of their radios and the guard frequency of one group interfered with voice transmission of the other group. The pilot fumbled with his life preserver in search of smoke flares. This was difficult due to sea state, darkness and leg straps not being tight enough, allowing his vest to ride high, making access difficult. Both groups of survivors used various signalling devices, including pencil flares, day/night flares, strobe lights and radios. They were eventually rescued by boat.

It is quite essential that 1) personnel be trained in the correct operation of their life preservers and life rafts, 2) they understand how to operate flares and radios, and 3) crewmembers and rescue specialists be aware of the difficulties of pulling injured people into life rafts and of hoisting people, either injured or relatively well into helicopters.

The aim of the training is to provide aircrew and passengers with the knowledge and skills required to be able to egress successfully from a helicopter ditched in water. It is recommended that ideally six, but not more than ten students at a time, be loaded on such a course to ensure both close supervision and that each student receives good practical training in all aspects of the equipment. As a prerequisite for the course, aircrew must have a current aircrew medical certificate and passengers must have passed a medical-equivalent to the USAF Class 1 Flight Physical. The major subjects should be covered, in three or four classroom lectures (depending on whether an underwater breathing apparatus is to be used) and one practical exercise in an underwater escape trainer, they are: 1) hazards of over water operation; 2) safety and survival equipment; 3) underwater breathing apparatus (if used); 4) pre-ditching preparation, and 5) underwater egress.

3.2 Hazards of Overwater Operation

A brief description of potential problems that may occur to the aircraft and result in ditching should be presented. They include mechanical, electric or hydraulic failure of engines, transmission and tail rotors, and the ever-present potential for fire. It should be emphasized that these problems tend to occur during the critical phases of flight, i.e., approach, missed approach, transit and hover.

Students should be aware of the environmental hazards, particularly thunderstorms, icing conditions, low visibility, and water, when a water landing has to take place. They should have a basic knowledge of sea states and of the causes and prevention of cold water-induced hypothermia.

Most important, the problem of underwater escape should then be described, i.e., in-rushing water, fire, smoke, fuel, darkness with no visual reference, and difficulties of releasing the restraint harness and of finding and releasing an escape hatch. Other factors that must be described are the problems of inevitable disorientation, the potential for being hampered by equipment, cold, injury, being pinned, being blocked by other passengers, and finally, reduced breath-holding ability, particularly in very cold water.

To complete this first classroom period, a description of the hazards that may occur after a successful underwater escape should be given, particularly the very real dangers of drowning, hypothermia, and potential injury that may occur during the rescue phase.

3.3 Safety and Survival Equipment

The equipment should be described in the second classroom period, divided into two sections, for personal and helicoper equipment.

3.3.1 Personal

Important points to teach about personal equipment are 1) the principles of the immersion or survival suit, how it should be worn, donning and doffing procedures, and importance of good care and attention; 2) the principles of the life preserver, its inspection and how it is operated; 3) the head set and/or helmet, how to obtain a proper fit, how to wear it, and use of visors; and 4) functional use of other equipment such as knives, flashlights, flares and personal items.

3.3.2 Helicopter

In the helicopter equipment section the helicopter seat and harness and its physical relationship to the stowage of all items of of safety equipment and communication should be described. Life rafts, emergency locator transmitters, fire extinguishers, first aid kits, sea anchors and tow lines, pyrotechnics kits, search and rescue packs and rescue gear should be individually described and, practically demonstrated. Then, a description and practical demonstration of the location and operation of the emergency exits and alternative routes, in case of being unable to reach the primary exit, should be given. It is very important that students are able to feel the amount of force required to open such exits, and that they activate such devices to their own and the instructor's satisfaction.

3.4 Underwater Breathing Apparatus

If an underwater breathing apparatus is to be used, then one classroom session should be devoted to its description, the requirements for pre-flight inspection, the method of operation and care of the unit. Specifically to be included are the technique of purging the regulator underwater and a caution about recharging the cylinders when there is a risk of contaminated air. Finally, a very short and simple physiology explanation should be given for the necessity to exhale during ascent after escape. This description is essential to prevent the trainee in the pool or the survivor in an accident suffering from an air embolism or burst lung.

3.5 Pre-ditching Preparation

This last classroom period should describe the paramount importance of the pre-flight briefing. For all crew and passengers, the pre-flight brief must include procedures to be taken in preparation for ditching, either with advanced or with very little or no warning. With only very little warning, the only course of action is to teach the crew and passengers to adopt a good crash position, and this should be practically demonstrated. With advanced warning, it is important that each person is taught how to 1) secure loose articles, 2) check their immersion suit and life preserver for correct donning and security, 3) ensure that their harness is secured tightly, 4) reconfirm escape exit location, 5) prepare to adopt a good crash position before impact.

For the aircrew, the lesson will also include the normal flight briefing items, the importance of crew responsibilities under normal operations and, during emergency procedures, the importance of the checklist and potential implications of deviating from the checklist, both before and after ditching.

For the passengers, the lesson will also teach the necessity to check and visually locate all parts of the personnel safety equipment, helicopter emergency equipment and helicopter emergency exits, and to reconfirm mentally normal emergency and abandonment procedures.

3.6 Underwater Egress

3.6.1 Without Emergency Breathing Apparatus

This section of the training must be conducted using some form of helicopter underwater escape trainer. In addition to two instructors, a minimum of two professional standby safety divers will be required in the pool at all times during the training sessions. Following the practical demonstration of how to abandon the helicopter, first in the upright surface position and then in the inverted position, the students must each demonstrate that they can successfully conduct the procedure themselves and then deploy all of their safety equipment at the surface. It is recommended that each student complete a minimum of two surface abandonments to ensure a thorough familarization of the equipment and procedures before attempting an abandoment in the inverted position.

The number of sequences that should be conducted in the inverted position will depend on the type of helicopter and the type of operation. As a minimum, it is recommended that the students be required to egress successfully from the helicopter configured to the type in which they will operate or, if a passenger, in which they will most likely travel. To achieve qualification, it is recommended that students successfully complete a minimum of four unassisted escapes, in sequence, from the designated position as follows:

(a) with no escape window/hatch in place while wearing life preserver and immersion suit, in day conditions;

(b) with escape hatches/windows and release mechanisms in place while wearing life preserver and immersion suit, in day conditions;

(c) with escape hatches and release mechanisms in place, while wearing full equipment (life preserver, immersion suit, helmet and backpack, if applicable), in day conditions, and

(d) with the escape hatches and release mechanisms in place, while wearing full equipment, in night conditions.

Additional training using secondary escape routes in the underwater escape trainer can also be added if desired. The complexity of the escape can also be enhanced by the addition of requirements to release life rafts and emergency locator transmitters before escape. This will all depend on the requirement of each helicopter operator.

3.6.2 With Emergency Breathing Apparatus

As has previously been mentioned, there has been much discussion concerning the safety of training personnel with an underwater breathing apparatus, particularly the possibilities of air embolism and ruptured lung. Recently the US Coastguard has put into service a simple, portable, inexpensive device, constructed from plastic plumbing pipe, called the Brooklyn Shallow Water Escape Trainer (SWET). It resembles a cube with no solid sides, the plastic pipes form the external margins (Figure 19). There are two additional bars fitted to enable the instructor to rotate the device to the inverted position. In the centre of the open cube a seat and harness is fitted; ahead of this, if required, a mounting can be placed for an emergency breathing device (if the device to be used is not man-mounted). In the open areas on either side of the seat outlined by the plastic pipe, it is possible to fit windows, hatches and release mechanisms that represent the type of helicopter used by the student. In order to prevent the student suffering from an air embolism or ruptured lung, buoyancy bags are fixed to the underside of the SWET. This ensures that the students' head to mid-thorax distance is never more than 105 Centimetres (3 feet) underwater. As a further precaution, training in the SWET is limited to a pool depth of 1.5 metres (5 feet).

The advantage of such a device, is that it is easily transportable, it can be picked up by two people and lowered into the pool; furthermore, it can be operated by the same two people - one performs the duty of device operator and the other the duties of the safety swimmer. The principal duties of the device operator are 1) to ensure all students have met all medical pre-requisites; 2) are properly dressed and briefed; 3) are strapped in and ready to be submerged and rotated; 4) if all these requirements are fulfilled, then to slowly rotate the device with the aid of the rotation bar and 5) be prepared to retract the device if the student has difficulties.

The principal duties of the safety swimmer (using a diver's face mask and snorkel) are: 1) to observe the students progress underwater; 2) in cases of emergency, signal to the device operator to initiate emergency retraction, and 3) to assist the student out of the device.

Because safety is paramount in training, it is recommended that subjects practice underwater escape breathing using only a SWET. It is advised that if an underwater breathing apparatus is to be used in a HUET or 9D5 type of trainer, then it should be done with extreme caution and with full medical monitoring. The SWET training should be as follows:

(1) With escape hatch removed, subject strapped in, subject activates flow of gas and breaths from the apparatus at the surface. Device operator inverts the SWET and, after thirty seconds of breathing underwater in the SWET, subject egresses through open hatch.

(2) With escape hatch in position, subject strapped in, subject activates flow of gas and breathes from the apparatus at the surface. Device operator inverts the SWET and, after thirty seconds breathing underwater, subject releases escape hatch and egresses.

(3) With escape hatch removed, underwater breathing apparatus stowed, subject strapped in, device operator inverts the SWET. The subject is then required to activate gas flow from the breathing apparatus, purge the regulator and breath from it for 30 seconds. Subject releases escape hatch and egresses.

(4) With escape hatch in position, underwater breathing apparatus stowed, subject strapped in, device operator inverts the SWET. The subject is then required to activate gas flow from breathing apparatus, purge the regulator and breath from it for 30 seconds. Subject releases escape hatch and egresses.

3.7 Performance Objectives

There are two performance objectives, the first is to demonstrate the ability to escape successfully from the underwater escape trainer in full equipment. This is measured by a simple pass/fail criteria. Each subject may be given three opportunities to achieve each of the four increasingly more difficult scenarios. A fail should be recorded if, after a third attempt of any scenario, a student cannot successfully egress the helicopter trainer from underwater configured for aircraft type and position.

If an underwater breathing apparatus is being used, then the second objective is to demonstrate the ability to escape from the SWET using the breathing apparatus. This is again measured by a simple pass/fail criteria. A fail should be recorded if, the

Figure 19. The Brooklyn Shallow Water Escape Trainer (SWET).
(Courtesy U.S. Coastguard and Survival Systems Ltd.
Dartmouth, N.S.)

subject cannot achieve any of the four level in the SWET after three attempts. The following accident scenario demonstrates yet again the success of such training:

> A Norwegian military Bell UH-13 was on a night-time search and rescue mission to a sinking yacht with two volunteer crew onboard as the regular SAR helicopter crew was on another mission. During first pick-up trial, the hook at the end of the hoist wire got caught in the boat and later broke leading to severe control problems. The pilot lost visual reference and the helicopter crashed with low nose and low speed. It immediately capsized and came to rest upside down in about two metres depth of water of 10°C temperature. Both crewmembers described the evacuation as very similar to what they had done during underwater escape training. The pilot put his left hand on the seatbelt and tried to find and pull the emergency egress handle on the right door with the other hand. He was not sure he had found the handle and instead located the normal door knob. He opened the right door in the regular fashion and got out. The flight engineer, who had been operating the hoist, was not strapped down during the crash and tried to support himself by tensing his arms and legs as he realized that the helicopter was crashing. He was caught by the inrushing water as the helicopter turned over and was probably sitting on the ceiling of the helicopter after it had come to rest. He stood up, disoriented, not aware that the helicopter had turned over. He freed himself from the monkey strap and got out probably through the same door as the pilot. Search and landing lights were still working and helped him find the escape route. A large air bubble inside the cabin was also a help.

3.8 Training Facilities

Single-placed underwater escape trainers, nicknamed Dilbert Dunkers, have been in service with the US Navy since the Second World War. However, these were designed only for fixed wing aircrew. Underwater breathing techniques in the cockpit were later added to the training and, to enhance this, the US Navy 9H19 apparatus was introduced into service for use in the shallow end of a pool prior to training aircrew in the fixed-wing underwater escape trainer where their standard aircraft panel-mounted regulator was fitted. In 1961, the US Marines built a prototype helicopter escape trainer and attempted to train combat troops.

It was discontinued for unknown reasons. In 1962, the Royal Navy put an escape trainer into operation and made training mandatory for all flight personnel.

In 1972, the USN re-established the requirement to provide practical underwater escape training (74); the first device, called the 9D5, was built by Burtek Incorporated, Tulsa, Oklahoma, and was commissioned at the Naval Aviation School's Command, Pensacola, Florida in 1978. Subsequently it was widely recommended for training of all USN helicopter pilots, and the USN currently have seven 9D5 trainers in service. The US Coast Guard train their personnel at the closest USN facility and have, in addition, as previously mentioned, introduced the SWET to teach the underwater breathing apparatus.

Very recently Dr. Allan at the R.A.F. Institute of Aviation Medicine (5) has built a simple helicopter underwater escape simulator. With this it is possible to carry out research into many of the problems of underwater escape such as underwater lighting, escape size hatches and interface of aircrew equipment.

The following helicopter underwater escape trainers are currently in service in the Western World (Figure 20).

Australia:	
- National Safety Council of Australia, Sale, Victoria, Woodside Petroleum, Port Headland.	Airframe of Bell 206
- Industrial Foundation of Accident Prevention, Freemantle, Western Australia.	Non-specific Mock-up
Canada:	
- Survival Systems, 110 Mount Hope Rd, Dartmouth, Nova Scotia.	HUET
- Memorial University, St. John's, Newfoundland.	HUET
France:	
- Centre d'Expérimentations Pratiques de l'Aéronautique Navale, Base d'Aéronautique Navale Fréjus - Saint Raphael, 83000 Toulon Naval.	Lynx simulated fuselage
Germany:	
- Naval Air Station 2859 Nordholz.	Modified 9D5

Italy:

- Base Elicotteri, Marina Militaire Aeroporto De Lunisarzana (La Spezia)	Modified Dilbert Dunker
- Base Elicotteri, Marina Militaire (Maristaeli) Aeroporto Di Catania, Fontanarossa, Sicilia	9D5

Norway:

- NUTEC, Gravdalsveien 255-5034 Ytre Laksevag, Bergen	HUET
- Tjeldsund Offshore Centre, Fjeldal 9440 Evenskjer, Tromso.	HUET

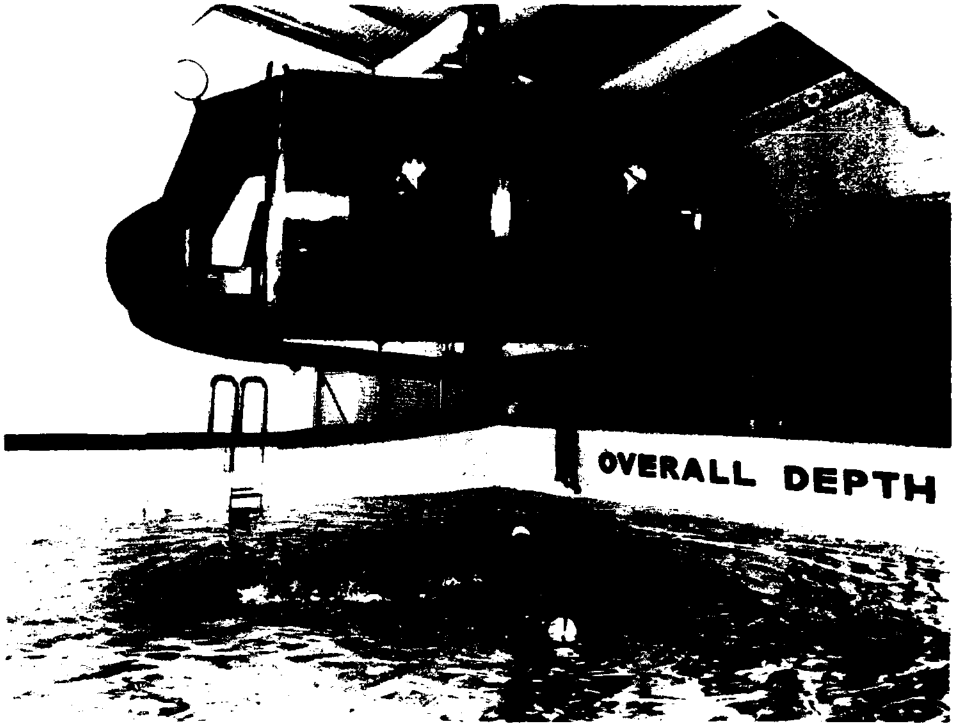
United Kingdom

- The Royal Navy Underwater Escape Training Unit, HMS Heron, Yeovilton, Devon.	Modified HUET
- Robert Gordon's Institute of Technology, Aberdeen Scotland.	HUET
- Royal Air Force Institute of Aviation Medicine, Farnborough, Hampshire.	Dr. Allan (prototype)

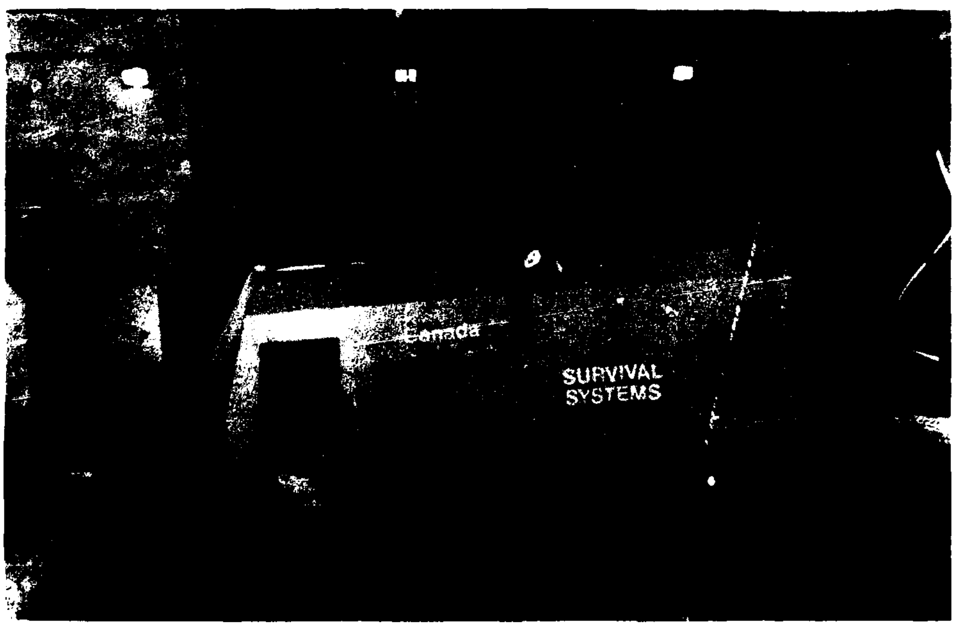
United States Naval Air Station

- NAS Lemoore, California.	9D5B
- NAS El Toro, California.	9D5B
- NAS Miramar, California.	9D5A
- NAS Pensacola, Florida.	9D5A
- NAS Jacksonville, Florida.	9D5A
- NAS Norfolk, Virginia.	9D5A
- NAS Cherry Point, North Carolina.	9D5A

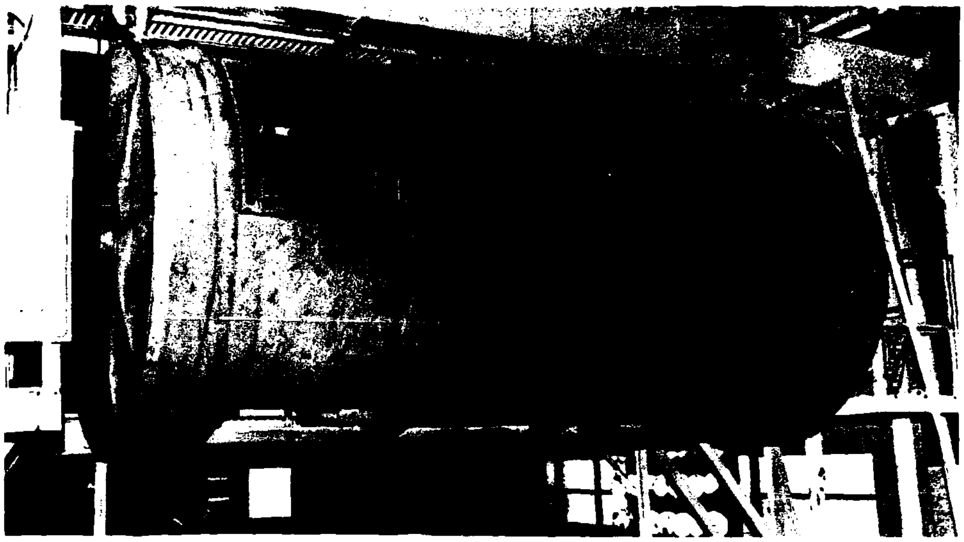
Figure 20. Typical types of helicopter underwater escape trainers.



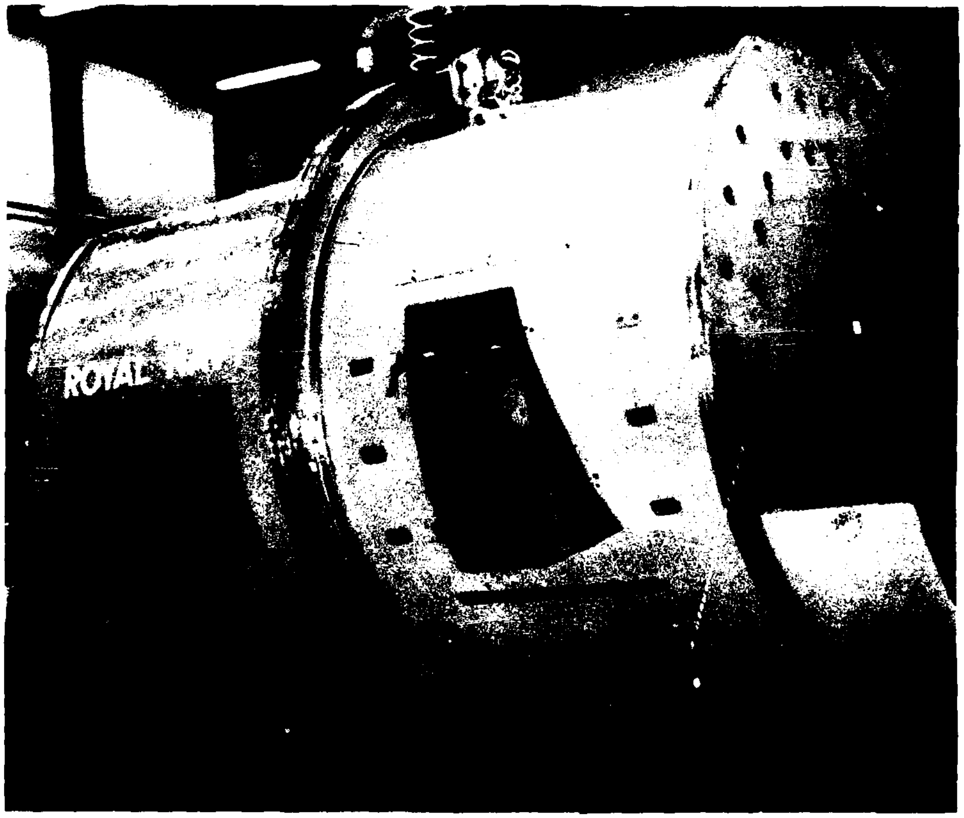
A. Robert Gordon's Institute of Technology, Aberdeen, Scotland HUET.



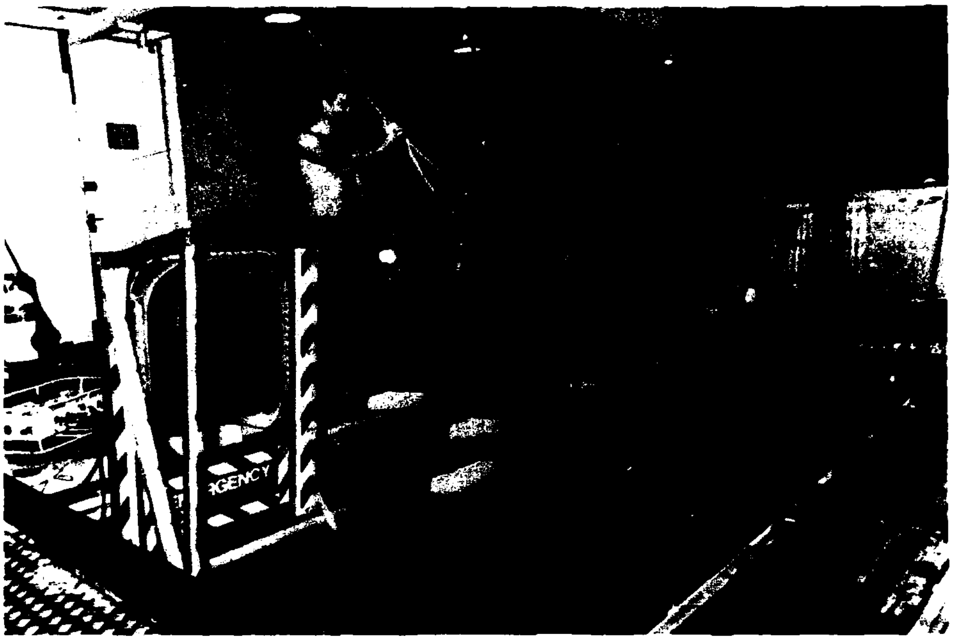
B. Survival Systems, Dartmouth, Nova Scotia. Modified HUET.



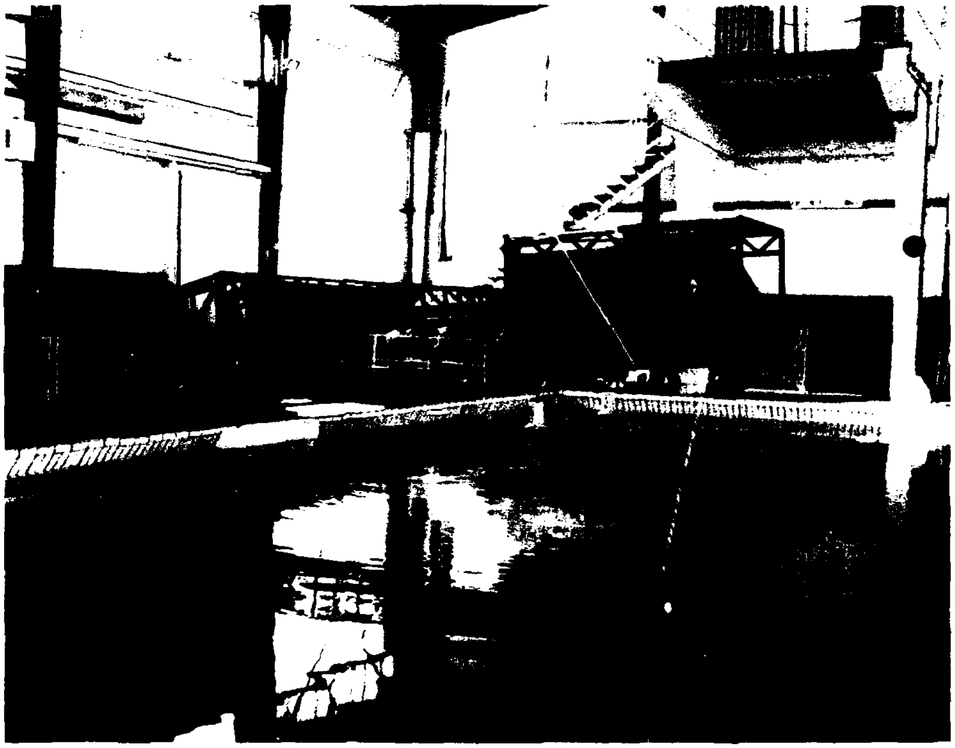
C. U.S. Navy Burtech 9D5 N.A.S. Pensacola, Florida.



D. Royal Navy, H.M.S. Heron, Yeovilton, Modified HUET.



E. Royal Air Force I.A.M. Farnborough - Dr Allan Experimental.



F. French Navy, Base d'Aéronautique Navale de Fréjus / St Raphael. Lynx simulated fuselage.

CHAPTER 4: CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

Military and civilian helicopter accident rates, either on a per hour or per flight basis, are significantly worse than those for modern jet transport. The crew and passengers of helicopters flying over water generally have less than one minute of warning of a ditching before they find themselves in the water. The helicopter is very unstable in water and will likely capsize if struck by a breaking wave of greater than 1.75 metres height. The probability of such an event happening in any ten minute period off the coast of the British Isles has been estimated to range from 0.3 to 11% depending on geographical area. Fifty percent of ditched helicopters invert and rapidly sink upon impact with the water. In military aviation, there has been an overall survival rate, on average, of about 80% in daylight and 65% in darkness. Some of these accidents are survivable, but little has been done to reduce the injury from contact or acceleration by introducing basic crashworthiness principles into the helicopter. If the crew and passengers survive the initial impact, then the greatest threat to survival is the potential for drowning. Drowning occurs as a result of one or several factors in combination, the most life threatening being rapid in-rushing water, sudden darkness, inevitable disorientation, inability to breath-hold long enough under water, and confusion over escape routes because there are no visual or tactile references leading to escape hatches.

Crew and passengers survival is enhanced if they have had a good pre-flight briefing, are sports or professional divers and, most important of all, have had practical professional training in underwater escape, and the correct crash position to adopt. Practical underwater escape training for aircrew, technical crew and frequent passengers flying in helicopters over water saves lives.

For current in-service helicopters, redesign of several structural parts of the helicopter will reduce fatalities, particularly the introduction of crashworthy seats and fourpoint restraint for everyone on board. Specifically, increasing the number of escape hatches, adding hatches in the deck, lengthening hatches to floor level, shortening the distance to travel from seat to escape hatch, simplifying hatch or window release mechanisms, making each window a push-out window, adding an underwater braille system that would guide survivors to the escape hatch by touch, and incorporating good underwater lighting would all improve the survival rate. Further increase in survival could be achieved by the addition of an underwater breathing apparatus or a built-in breathing system (BIBS) and the fitting of externally-mounted self-stabilizing multi-seat life rafts that jettison automatically on ditching and are marked by a light after inflation.

For newly designed helicopters, there should be a systematic approach to crashworthiness where the interaction of all crashworthy elements are considered - seats, landing gear, fuselage, layout of consoles, escape path, flotation, lighting etc. Similarly, life rafts, if deployed, have not always inflated and are prone to puncture and being rolled on top of by a sinking helicopter.

Even after escape, the final rescue phase is not without hazard. Hypothermia is a risk in the ocean or life raft, and hoisting in the vertical position seriously compromises the cardiovascular system under such circumstances.

4.2 Recommendations

4.2.1 Improvement to cabins of in-service helicopters

Helicopter manufacturers should enhance cockpit safety by adding crashworthy seats and at least four-point harnesses for all occupants. The cabin should be redesigned to shorten escape routes and increase the number of escape apertures, particularly in the floor. Furthermore, an underwater braille system should be developed for survivors to use to locate an escape aperture.

For guidance to escape hatches, all cabins of helicopters flying over water should be fitted with a stroboscopic light bar.

4.2.2 Improvement to life support equipment

To increase breath-holding ability, emergency underwater breathing apparatus should also be fitted to helicopters flying over water.

At major refits and for all newly acquired service helicopters, life rafts must be mounted external to the hull which could be automatically jettisoned, inflated, and illuminated.

Life preservers and life raft manufacturers should strive to provide the highest possible reliability. Funding should be provided to immersion suit manufacturers to conceive and develop better types of immersion suits.

Equipment and procedures of all search and rescue squadrons should be changed so that survivors will be hoisted in the horizontal or semi-horizontal position.

4.2.3 Training

Helicopter underwater escape training should be mandatory for all aircrew and, whenever possible for passengers flying overwater operations. Included in this should be the practical demonstration of the correct crash positions to adopt.

If an emergency breathing system is part of the equipment, the practical use of it should be included in the training using a Shallow Water Escape Trainer. The emergency breathing system should be used with extreme caution in a HUET or 9D5 type of trainer and only then with full medical supervision.

4.2.4 Future helicopter design

A systematic approach to crashworthiness should be taken. Specifically to be included should be the seats, landing gear, fuselage, layout of consoles and instrument panels, escape path, flotation lighting and life support equipment.

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This AGARDograph has been truly an exercise in international co-operation, particularly as some of the information on aircraft accidents was "priviledged" and could not be published in its original format. I have many people to thank for all their hard work in finding me a very wide range of information.

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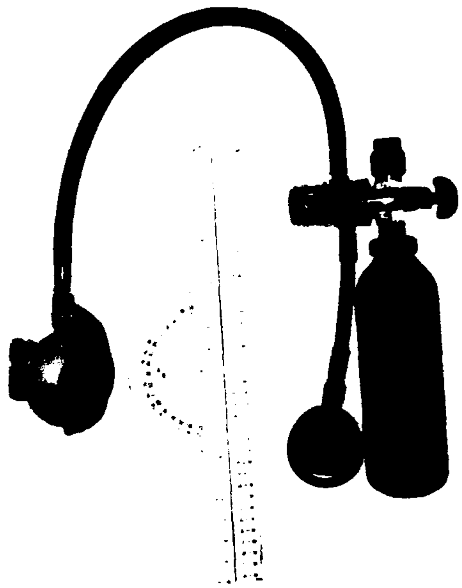
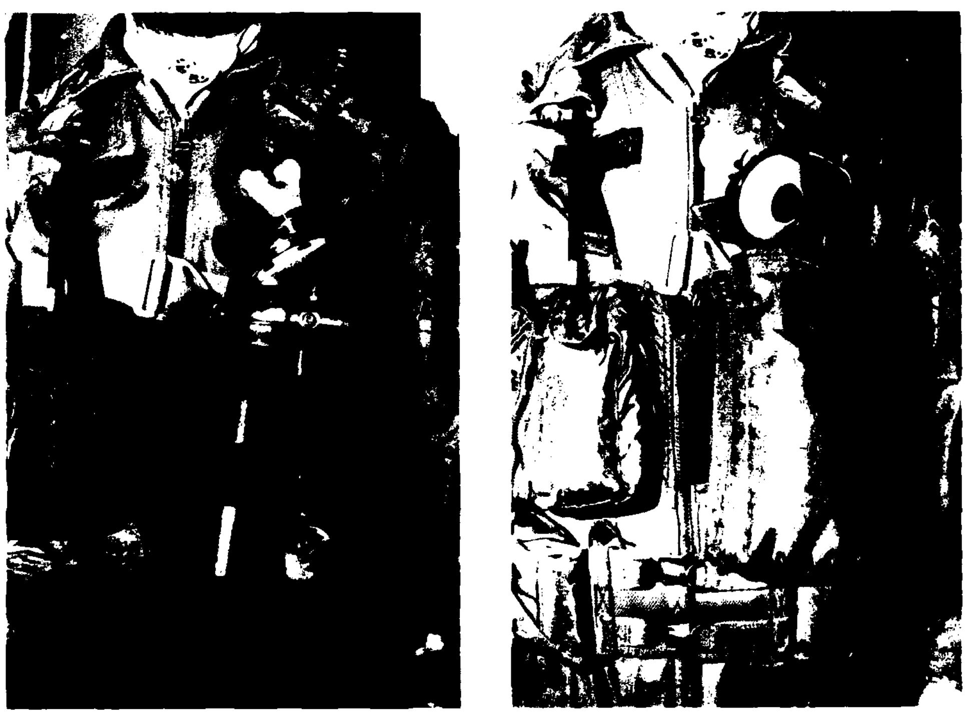
Annex A. Figure 21.

Italian Navy Helicopter Underwater Escape System.

This system is made by CRESSI and fits on the lifejacket. The cylinder measures 29 cm long by 6.3 cm in diameter; fully charged to 165 Atmospheres it weighs 1880 grams.





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Helicopter escape	Underwater escape
Helicopter escape training	Underwater helicopter lighting

14. Abstract

This AGARDograph describes the worldwide incidence of military and civilian over-water helicopter accidents and the problems related to survival. It reviews the typical accident scenario from the moment the occupant steps on board the helicopter and the pre-flight briefing through to the accident itself, the difficulties with escape (commonly from underwater and in darkness), to the rescue and return safe and sound to dry land. It also proposes improvements to crashworthiness and life support equipment in current in-service and future helicopters and a syllabus for underwater escape training.

This AGARDograph was sponsored by the AGARD Aerospace Medical Panel.

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